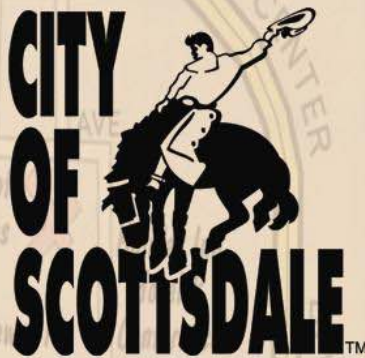


FINAL REPORT

INDIAN SCHOOL ROAD CORRIDOR INTELLIGENT TRANSPORTATION SYSTEM EVALUATION

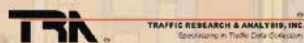
APRIL 2003

PREPARED FOR



PREPARED BY

BRW



Final Report

Indian School Road Corridor Intelligent Transportation System Evaluation

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April 2003

EXECUTIVE SUMMARY

The evaluation of the Indian School Road Intelligent Transportation System indicates that even after only six months, while operational strategies are still being perfected, the system has greatly enhanced the City's traffic management capabilities and has provided significant benefits to the public. These findings validate the City's move to a more responsive, proactive and hands-on traffic management philosophy and support expansion of the ITS program.

Indian School Road ITS System

The 3-mile Indian School ITS includes the following elements:

- Closed-circuit television (CCTV) surveillance cameras to observe traffic conditions in real-time.
- Centralized traffic signal control system that allows remote modifications to traffic signal timing plans.
- Roadside variable message signs (VMS) for providing information to travelers.
- The Traffic Management Center (TMC) that provides a focal point for command and control.
- Intersection traffic detectors that provide data needed by the computerized traffic signal control units.

Evaluation Approach

The system became operational in August 2002. The evaluation started at that time and concluded in February 2003. The evaluation featured before-after analysis of travel times and intersection delays along Indian School Road from Pima Road to 64th Street, as well as case study analyses of the uses and benefits of the various ITS technologies and techniques. In addition to the travel time and delay study, the evaluation included:

- Interviews with police and TMC staff.
- Direct observation of TMC operations under various conditions.
- Analysis of detailed traffic signal timing plan modification and VMS logs maintained by the TMC staff.
- Staff labor savings analysis of ITS vs. traditional signal timing plan updates.

Results

The evaluation yielded a wealth of useful information including data that supports the estimation of annual public benefits as well as valuable lessons learned that improve the effectiveness of the City's ITS operations. Observed benefits include:

- Corridor travel time reductions on Indian School Road as a result of traffic signal timing updates (reductions of up to 64 seconds over the 3-mile corridor, depending on direction and time of day).
- Police labor savings for Barrett-Jackson/Phoenix Open special event traffic management (reduced number of officers in the field by approximately 30/day).

- Staff productivity increases for conducting “strategic” traffic signal timing plan modifications at individual intersections (more than double the number per year while still spending more time refining each plan modification). “Strategic” plan updates adjust the basic timing plans to fit prevailing day-to-day traffic conditions as closely as possible.

There are also inferred benefits. These are based on the TMC staff’s documented utilization of the technologies but which rely on assumptions regarding the impacts of those actions. These benefits consist of traffic delay reductions under day-to-day, special event, incident and construction conditions. These benefits result from real-time “tactical” traffic signal timing plan modifications and posting of variable messages signs that are expected to encourage travelers to avoid congested areas.

Table ES-1 summarizes the annual public benefits associated with the observed and hypothesized impacts. These benefits total \$2.47 million.

Implications

One of the most important overall benefits of the ITS is that it promotes coordination of traffic management between law enforcement and traffic operations, which reduces traveler delays and improves incident response. Placement of a police officer in the TMC during the Barrett-Jackson/Phoenix Open week has been quite effective and the addition of an officer full-time would provide additional benefits, especially during major incidents. In the long-term, coordination can be even further improved through the possible co-location of the TMC and police dispatch and even linking traffic management systems with police computerized dispatch systems.

Benefits occur only when ITS is actively utilized by competent staff, and they are the most important part of the system. CCTV cameras and the centralized traffic signal system are the most critical equipment. Cameras provide the information that is required for any effective traffic management strategy and unlock the enormous potential inherent in the signal system’s capability to remotely implement real-time traffic signal timing plan changes.

VMS provide the ability to convey important information directly to travelers. This evaluation affirms that VMS spacing is critical. It is important that the signs be located far enough in advance of major diversion points to allow drivers to respond to the VMS message. The effectiveness of VMS is increased when CCTV cameras are available to verify conditions referred to in the VMS message. Additional information on driver reactions to VMS and the associated traffic impacts would be useful, both to verify the assumptions of this analysis and to further inform the City’s operating strategy.

Traditional in-pavement inductive loop traffic detectors performed better than the two alternative technologies evaluated (video and radar) and remain the best choice for intersection traffic detection. However, due to the traffic disruptions associated with loop maintenance, it is recommended that consideration of alternative detector technologies continue, as the video and radar technologies mature and as new technologies become available.

**Table ES-1
Summary of Estimated Community Benefits**

Impact		Person-Hours of Delay	Gallons of Fuel	Vehicle Pollutant Emissions	Total Dollar Value of Benefits
Day-to-Day Traffic Congestion Signal Timing Modifications	Reductions in vehicle delay due to real-time signal timing modifications. (500 modifications/year)	152,778	69,445	20,139	\$2,114,045
Additional Periodic Signal Timing Plan Updates at Individual intersections	Reductions in the time required for updates using CCTV for field observations. (50 more updates/year)	9,167	4,167	1,208	\$119,171
Barrett-Jackson/Phoenix Open Special Event Traffic Management	Reductions in vehicle delay due to real-time signal timing modifications.	155	78	10	\$2,144
	Reductions in law enforcement field labor hours (save 2,976 person-hours @\$36/hr)				\$107,136
Indian School Road Corridor Timing Plan Update	Reductions in corridor travel time.	5,477	5,477	103	\$93,423
Incidents and Construction	Reductions in vehicle delay due to real-time signal timing modifications. (200 modifications/year)	612	278	81	\$8,456
	Reductions in vehicle delay due to traffic diversions facilitated by VMS. (170 messages/year)	1,558	779	226	\$21,690
Total		169,747	80,224	21,767	\$2,466,065

ITS compliments rather than substitutes for physical roadway improvements. However, the frequent and efficient modifications to traffic signal timing plans made possible with ITS can serve as an effective interim measure until funding for roadway expansion becomes available. ITS technologies should be evaluated before considering more expensive physical improvements. ITS also effectively addresses incident, construction and special event congestion that is not cost effectively addressed through physical improvements (roadways are not designed to accommodate non-recurring spikes in traffic congestion associated with these situations). The benefits of ITS are expected to begin tailing off once traffic volumes reach some absolute roadway capacity. Conversely, the impact of ITS is expected to be less on roads with significant excess physical capacity. However, conditions are expected to be better with ITS than without it under any circumstances.

Expansion of the ITS will improve the ability to implement area-wide traveler information strategies, which are currently constrained by the lack of CCTV cameras on alternate routes. Expansion of the City's ITS infrastructure should proceed no faster than staff can utilize it. That is, staff training, and eventually staff increases, should occur in conjunction with system expansion. Expansion should focus on the highest volume corridors, especially those that serve a major special event venue or other traffic generators that experience marked cyclical spikes in traffic volumes, like major shopping malls during the holidays.

ITS techniques are still being refined and new technologies are always becoming available. It is important to validate and expand the findings of this study. The City is strongly encouraged to continue to evaluate ITS as the City's system is expanded. Recommended metrics include: travel times; intersection average vehicle delay; accident frequency, duration and type (primary vs. secondary and cause); public perception of traveler information strategies (e.g., VMS); and VMS and traffic signal logs. Future ITS assessments will be made easier through the introduction of the following enhancements:

- electronic logs for VMS and signal timing modifications;
- automated archiving of CCTV image and traffic detector data; and
- differentiation of secondary accidents on police accident reports.

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1.0 INTRODUCTION

This report presents results of the evaluation of the Intelligent Transportation System (ITS) implemented by the City of Scottsdale along Indian School Road in the summer of 2002. This ITS project is a *traffic management system*. The system includes CCTV cameras to observe traffic conditions, a centralized traffic signal control system that allows remote modifications to traffic signals, variable message signs to provide information to travelers, and the Traffic Management Center, which provides a focal point for command and control. The equipment is located along the 3-mile Indian School Road corridor, between 64th Street and Pima Road. The devices are operated from a Traffic Management Center (TMC) located at the City of Scottsdale administrative offices. Fiber optic cable provides the link between the TMC and the various devices. The components of the system are further described in Section 1.2.

The Indian School project is the first corridor-oriented, intensive ITS implementation in the City. It provides the opportunity to validate the effectiveness of proven technologies like surveillance cameras, to investigate the potential of new technologies that may represent a potential improvement over existing technologies, and to improve the City's understanding of how these technologies can be most effectively utilized.

The Indian School Road traffic management system allows the City to take a much more proactive, "hands on" approach to maintaining traffic flow and facilitates both "strategic" and "tactical" responses. Strategic actions include periodic updates of basic traffic signal timing plans to fit prevailing day-to-day traffic conditions. Tactical actions include short term modifications to traffic signal timing plans and posting variable message sign messages in response to "hot spot" traffic congestion, traffic accidents, special events or construction. The technology elevates traffic staff responsibilities to include overall on-street performance, including working with law enforcement and other transportation system operators, rather than limiting them to traffic signal issues alone. Such an approach is needed to address increasing traffic volumes and congestion. As traffic becomes more congested, which occurs gradually over time as well as during roadway maintenance and special events, traffic flow becomes more volatile. Even minor traffic accidents or other incidents like vehicle breakdowns can cause major disruptions. The Indian School Road traffic management system provides the City with the tools necessary to minimize these impacts by quickly identifying problems and taking effective actions to address them, including coordinating closely with law enforcement, other traffic agencies like the Arizona Department of Transportation, and providing travelers with the information they need to either avoid or prepare for the problems.

Increases in traffic volumes and congestion and changing traffic patterns also increase the importance of frequent adjustments to traffic signal timing plans. Timing plans have a tremendous influence on traffic flow. A good "fit" between the plan and the traffic patterns minimizes delay, whereas an outdated, poor fitting plan can result in significant congestion. The Indian School Road traffic management system allows the City to update timing plans much more quickly and effectively than is possible using traditional, more labor intensive approaches.

The Indian School Road ITS project is a reflection of the City's on-going efforts to apply the most effective technology to meeting the needs of the traveling public while preserving the high quality of life and economic viability that distinguishes Scottsdale. The traffic management system represents the next step in the evolution of traffic management strategies, a step that brings the City's traffic management efforts fully into the computer and communications age, in the same way that computers, the Internet, and other current technologies have been applied in

support of other City services. The new technologies and techniques do not substitute for basic roadway capacity, that is, having the necessary number of lanes. Rather, they provide the means to promote traffic flow when traffic volumes approach the limits of that roadway capacity, which is the case on many of the City's most important roads.

In implementing ITS on the Indian School Road corridor, the City joins the other progressive and responsible jurisdictions around the Phoenix region and the United States that have accepted the challenge and responsibility to move beyond the passive traffic management approaches of the past. Past approaches were typically limited to providing and maintaining roads and traffic control equipment (signs and signals), but lacked any hands-on, real-time oversight or intervention. The traffic management tools and techniques like the ones implemented on Indian School Road represent the appropriate response to increasing traffic challenges and allow the City to provide an enhanced service to the public.

The usefulness of the technologies implemented on Indian School Road has already been established, both by other agencies around the world and through the City's previous implementation of these technologies at other locations. Overall, however, the science and/or art of how best to utilize these systems is still evolving. As the first intensive, corridor-level implementation of an ITS traffic management system, the City has recognized the Indian School project as an important opportunity to expand their understanding of how best to implement and operate these tools. This evaluation, which occurred immediately upon completion of the project, identifies important benefits. However, it is also understood that these benefits will increase over time and the full value of the system will be revealed as the City traffic staff further refine their traffic management strategies and incorporate the lessons learned from this project.

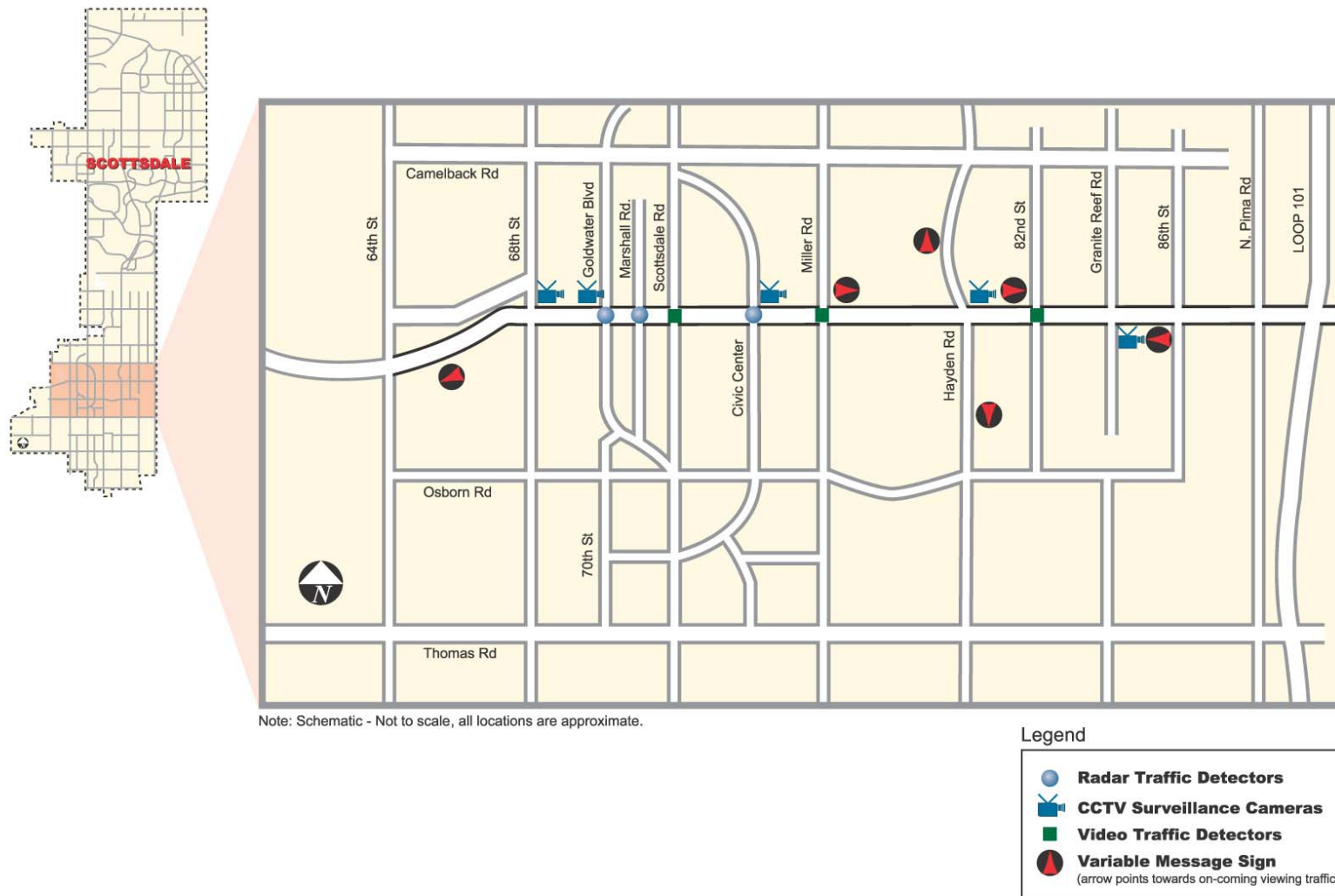
1.1 Project Description

1.1.1 Indian School Road Corridor

Indian School Road is a major east-west roadway in south-central Scottsdale. Figure 1 illustrates the study corridor and the ITS project elements, which are described in more detail in Section 1.1.2.

The far western and eastern ends of the approximately 3-mile study corridor are lined primarily with residential development. The central portion of the corridor is more densely developed with commercial uses, including the Old Town Scottsdale shopping district in the vicinity of Goldwater Boulevard and Scottsdale Road, and civic facilities located between Scottsdale Road and Miller Road. A major regional freeway, the Loop 101 Pima Freeway, borders the eastern end of the corridor, less than ½-mile east of Pima Road, and includes an interchange with Indian School Road.

Along most of the corridor, Indian School Road is a four-lane roadway, with two through lanes in each direction. Most signalized intersections have single left turn lanes in all directions. Some of the more major signalized intersections include dual left turn lanes and separate right turn lanes. The posted speed is 35 mph with the exception of the far eastern end of the corridor, where the posted speed is 40 mph. The 3-mile study corridor includes 14 traffic signals, which are closely spaced in the central portion of the corridor (between Goldwater Boulevard and 75th Street) where the average spacing is one signal every 1/8-mile.



Indian School Road Corridor ITS System

BRW

Figure 1: Project Study Area and ITS Field Devices

Average daily traffic volumes along the corridor range from approximately 20,000 vehicles per day to 40,000 vehicles per day on the eastern end of the corridor. The highest volumes are found along the eastern portion of the corridor, between Miller Road and Pima Road. Year-to-year changes in average daily traffic volumes over the last decade have varied, averaging a 2% annual increase. A major increase in volumes along the eastern portion of the corridor (east of Miller Road) occurred between the 1998 and 1999-2000 City traffic counts. This increase is probably related to the opening of the Indian School Road/Loop 101 Pima Freeway interchange.

The major intersection of Indian School and Hayden Roads, located in the east central portion of the study corridor, was reconstructed during the evaluation period. Dedicated right turn lanes and a second left turn lane were added on all four approaches. The construction project began around the same time the Indian School Road ITS project became operational, in August-September 2002. The project was completed in March 2003. The construction project did impact the evaluation, as described in Sections 2.0 and 3.0.

Camelback Road is the major parallel road located 0.5 mile north of Indian School Road. Camelback Road does not interchange with the freeway. Overall, traffic volumes along Camelback Road are similar to those on Indian School Road in the study corridor, although volumes are higher on Camelback on the west central portion in the vicinity of the large Fashion Square regional mall. Thomas Road is the major parallel road located 1 mile south of Indian School Road and does interchange with the freeway. Traffic volumes on Thomas Road are similar to those on Indian School.

1.1.2 Indian School Road ITS Traffic Management System

The Indian School Road ITS project field infrastructure is described below and shown in Figure 2.

- Fiber optic communications cable linking the City of Scottsdale Traffic Management Center (TMC) with field devices. The fiber includes significant additional capacity beyond that required to support the current ITS application. If desired, this capacity could be used to support additional traffic management activities, or possible transit information displays (e.g., “next bus” arrival time signs), or support other City communication needs.
- Six (6) light emitting diode (LED) variable message signs (VMS), approximately 8 feet x 4 feet, 12 inches deep, mounted on 22-foot high poles, capable of displaying three lines of text. Two of the six signs, the ones located on Hayden Road north and south of Indian School, did not become operational until very late in the evaluation period, due to communications systems issues that resulted from the Hayden Road/Indian School Road reconstruction project. That project occurred concurrently with the evaluation.
- Five (5) closed-circuit television (CCTV) cameras, with 360-degree pan-tilt-zoom capability, mounted on traffic signal or street light poles, with a maximum viewing range of 1 mile in any direction.



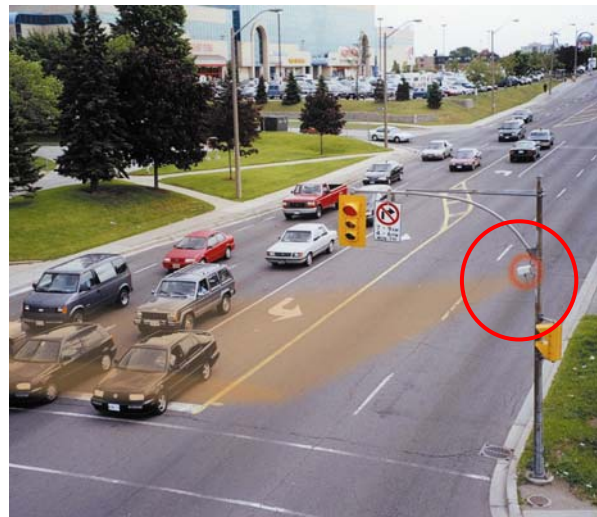
**CCTV camera at Indian School Road/
Goldwater Boulevard**



**Video traffic detector
at Indian School/82nd Street**



**Variable message sign on Indian School
Road facing westbound traffic, west of 82nd
Street**



**Radar traffic detector (photo provided by vendor;
this particular installation is not in Scottsdale)**

**Figure 2. Indian School Road VMS, CCTV Cameras,
and Video and Radar Traffic Detectors**

- Three intersections equipped with radar traffic detectors (four units per intersection). Each detector provides vehicle presence detection for no less than three lanes of traffic. The detector information is an input to the computers that are housed in the roadside cabinet and that control the traffic signals. The radar detectors were investigated as a potential alternative to the traditional detection method which utilizes inductive loops—loops of wire embedded in the traveled lanes of the roadway. The radar detectors, which are mounted above the roadway on the traffic signal poles, provide the advantage of being maintainable without disruptions to traffic.
- Three intersections equipped with video traffic detectors (four units per intersection). Each detector provides detection for all approach lanes for a given intersection approach. The video detectors are another alternative to detection loops which, being mounted above the roadway on the signal poles, offers the advantage of being maintainable without disrupting traffic. The video detectors offer another benefit. Video footage from the detectors can be displayed at the TMC, providing some limited surveillance monitoring capability. Unlike the CCTV cameras, the video traffic detectors do not pan, tilt or zoom and therefore offer only a single view.

Concurrent with the implementation of the field infrastructure, a number of enhancements have been made to the City of Scottsdale TMC to support the Indian School Road ITS and other traffic management activities. The TMC is located on the second floor of the City of Scottsdale administrative offices, at the southeast corner of Indian School Road and Drinkwater Boulevard. Improvements to the TMC include an upgraded video display, for monitoring the CCTV cameras, and various computing and communications system enhancements. The TMC also houses the City's centralized traffic signal control system that allows TMC staff to monitor traffic signal operations and upload and download timing plans. The TMC is staffed Monday-Friday from approximately 6:00 AM – 6:00 PM. Typically, only one staff member is dedicated to TMC duty at any given time, although two other traffic staff members with offices adjoining the TMC often support that position.



Figure 3. Video Display Wall at TMC

The total cost of the Indian School Road ITS is approximately \$2.98 million. Approximately \$1.67 million was provided with Federal transportation funds. The approximately \$1.31 million in City funds used for the project are capital funds derived from the 0.2% sales tax. The cost of the field infrastructure for the 3-mile corridor, including the fiber communications, amounts to about \$450,000 per mile.

1.2 Regional and National Context for ITS

Over the last 10 years, the United States Department of Transportation (USDOT) has strongly promoted the implementation of ITS and has provided funding incentives and flexibility to public agencies to do so. The application of current technologies for traffic management is a movement at the global level, with most industrial countries pursuing ITS strategies, with several of them leading the U.S.

Arizona and the greater Phoenix area have been among the leaders in implementing ITS in the U.S., including traffic management systems on freeways and local streets. The regional ITS program, AZTech, is led by a coalition of area agencies, including the City of Scottsdale. AZTech has promoted implementation of systems like the one on Indian School Road and the City's investment represents participation in a valley-wide movement. The regional vision includes linking local TMC's, like the one in Scottsdale, with other municipal, county and state TMC's. This network will allow agencies to share traffic information and will facilitate regional coordinated traffic management.

Participation in the AZTech regional ITS program also provides access to additional funding. Federal traffic management funding programs often place a premium on coordinated, multi-jurisdictional projects and access to funds administered through the Maricopa Association of Governments (MAG) is enhanced through the AZTech coordination.

1.3 Project Objectives

There are two general classes of objectives for the Indian School Road Corridor ITS project. The first class may be considered the primary or "ultimate" objectives and focus traffic impacts like delay and safety. The second class of objective is also important, but can be viewed more as "side benefits".

The three primary, traffic-related objectives of the Indian School Road ITS are:

1. Reduce delay and improve safety at signalized intersections during construction projects.
2. Reduce traffic delay and improve safety surrounding traffic incident and special events.
3. Reduce traffic delay and travel times and improve safety at signalized intersections during day-to-day conditions.

The specific mechanisms to achieve these objectives and the contribution of the various ITS components are described in Table 1.

Table 1
Project Traffic Objectives and ITS Contributions

Primary Project Objective	Mechanism to Achieve Objective	ITS Contributions
1. Reduce delay and improve safety at signalized intersections during construction projects.	Implement more effective (less delay, fewer stops and fewer rear-end accidents) traffic signal timing plans customized for specific traffic control scenarios, which can change daily, and implement the plans more frequently.	Remote observations using cameras to identify the need for timing plan changes, and evaluating the impact of the changes, is much more efficient than on-site observation and provides staff the ability to devote more time to fine-tuning plans, making them more effective.
		Implement timing plan changes remotely from the TMC using the central signal system saves time and allows resources to be devoted to developing better plans.
2. Reduce traffic delay and improve safety surrounding traffic incidents and special events.	Reduce the volume of traffic entering incident scenes or special event areas by facilitating detours, and/or improve driver attentiveness through the areas.	Cameras provide a source of real-time information on which to base decisions about the need for detours or timing plan changes. This information would typically not otherwise be available, and therefore far fewer, and less effective, mitigations would be implemented.
		Posting messages on variable message signs provides for direct communication with travelers that would not otherwise be possible. Messages may be posted advising travelers to avoid the incident scene, or to prepare for delays.
	Reduce the delay at signalized intersections impacted by the incident itself, or by detouring traffic.	Cameras provide a source of real-time information on which to base decisions about the need for detours or timing plan changes. This information would typically not otherwise be available, and therefore far fewer, and less effective, mitigations would be implemented.

Table 1
Project Traffic Objectives and ITS Contributions

Primary Project Objective	Mechanism to Achieve Objective	ITS Contributions
		The centralized signal system and cameras provide the means to implement and fine-tune modifications to traffic signal timing plans much more quickly. The ability to view conditions and make changes remotely eliminates the time-consuming on-site traffic observations that are otherwise required.
	Facilitate effective incident clean-up by emergency responders by reducing the volume of traffic entering the scene and providing information to responders.	Cameras allow traffic staff to monitor conditions and collect and share useful information with emergency responders.
		Posting messages on variable message signs provides for direct communication with travelers that would not otherwise be possible. Messages may be posted advising travelers to avoid the incident scene or to prepare for delays.
3. Reduce traffic delay and travel times and improve safety at signalized intersections during normal day-to-day conditions.	Implement more effective (less delay, fewer stops and fewer rear-end accidents) traffic signal timing plans in response to changes in traffic volumes and patterns (i.e., periodic traffic signal timing plan updates).	Using cameras to remotely identify the need for signal timing plan changes and evaluate the impact of the changes, is much more efficient than on-site observation and provides staff the ability to devote more time to perfecting plans, making them more effective.
		Implement timing plan changes remotely from the TMC using the central signal system saves time and allows resources to be devoted to developing better signal timing plans.

Table 1
Project Traffic Objectives and ITS Contributions

Primary Project Objective	Mechanism to Achieve Objective	ITS Contributions
	Implement more periodic traffic signal timing plan updates by increasing the efficiency of the process.	Using cameras to identify the need for plan changes, and evaluating the impact of the changes, is much more efficient than on-site observation and allows staff to implement changes more quickly.
		Implementing timing plan changes remotely from the TMC using the central signal system saves time and allows resources to be devoted to implementing more updates.
	Improve responsiveness to the public and reduce traffic delay by reducing the lag time between recognition/notification of a signal timing problem and implementation of a timing plan modification.	Using cameras and the central signal system , traffic staff can make signal timing plan changes immediately, improving traffic operations and providing the public with a very responsive, high quality of service. This improved responsiveness is realized through the elimination of the field observations of traffic conditions that are necessary when cameras are not available.

“Side benefits”, or secondary objectives of the Indian School Road project include the following:

1. **Availability of the fiber optic communications infrastructure** implemented as part of the ITS projects can be used to provide a high-speed/high-capacity, dedicated communications for a wide range of potential future municipal applications, including the City’s Information Systems department, library, etc. The communications infrastructure could also support roadside transit passenger information displays, including signs that can display the estimated arrival time of the next bus, if and when such features may be considered.
2. Availability of the **advanced traffic signal controllers**, implemented as part of the ITS project, provide the capability for emergency vehicle preemption. They also could support priority treatments for transit vehicles (e.g., slightly extending green time to buses that are behind schedule), if and when such a measure may be considered.
3. Availability of the infrastructure, established through projects like the Indian School Road ITS project, provide the tools needed to conduct sophisticated, **real-time traffic management on a system-wide basis**, in the future. As CCTV cameras, traffic detectors, and VMS are implemented on numerous corridors, traffic operations staff can monitor traffic conditions and post messages to alter driver behavior. Utilization of system capacity can thus be maximized by facilitating real-time diversions from more congested roads to less congested roads.

There are additional important objectives associated with the evaluation of the Indian School project and the project experience overall, as described in Section 1.4.

1.4 Evaluation Objectives

The evaluation is structured primarily as a before-after study. In the case of the travel time and delay analysis, quantitative traffic data pre- and post-ITS deployment are compared. For other analyses, like the ones of special events and incidents, ITS-enabled approaches and impacts are contrasted with the pre-ITS conditions. The following objectives for the Indian School Corridor ITS evaluation have been established:

1. Document whether the primary project objectives have been achieved, including the type, magnitude, and explanation for various **impacts**.
2. Provide TMC staff with **feedback** (i.e., what works, what does not, how, when and where) that will allow them to improve the effectiveness of City ITS investments, existing and future.
3. Provide City senior management with information to guide and support future transportation **investment decisions**. This includes providing an understanding of:

- a. Documented and potential ITS *benefits*, including identification of appropriate metrics with which to estimate the impact of potential ITS investments and to evaluate the impact of future investments.
- b. The *role* of ITS investments in the City's overall transportation strategy, including ITS contributions to the following City council goals and objectives:
 - Enhance and protect a diverse, family-oriented community where neighborhoods are safe and well maintained.
 - Preserve the character and environment of Scottsdale.
 - Provide for the safe, efficient and affordable movement of people and goods.
 - Position Scottsdale for long-term economic prosperity by diversifying our economic resources.
 - Coordinate planning to balance infrastructure and resource needs within budget.
 - Make government accessible, responsive and accountable so that pragmatic decisions reflecting community input and expectations are made.
 - Ensure Scottsdale is fiscally responsible and fair in its management of taxpayer money and assets.

2.0 EVALUATION METHODOLOGY

The evaluation was conducted September 1, 2002 through March 10, 2003, a period of approximately 6-1/2 months. The evaluation included a number of analyses that can be generally organized into four categories corresponding to the primary applications for the Indian School Road ITS:

1. Tactical responses to incidents, construction, and special events.
2. Strategic traffic signal timing plan updates at individual intersections.
3. Strategic traffic signal timing plan updates along corridors.
4. Institutional and technical lessons learned

Based on the findings of these analyses, conclusions have been developed which pertain to the overall role of ITS in the City's transportation strategy and efforts to meet community goals and objectives.

2.1 Tactical Responses to Incidents, Construction and Special Events

The utility of the Indian School Road ITS in facilitating tactical traffic management (that is, managing short-term incidents, construction, and special events) was assessed using three techniques: observations at the TMC, analysis of traffic management logs, and debriefings with police and traffic operations personnel.

2.1.1 Observations at the TMC

Throughout the evaluation, the evaluation team spent several hours at the TMC observing first-hand the use of the system by TMC staff. CCTV surveillance camera images provided direct visual evidence of the benefits of various traffic management actions. Intensive TMC observation was conducted during the week of the Phoenix Open golf tournament in January 2003. Many hours of video recordings of TMC activities during various traffic incidents were also collected and reviewed.

2.1.2 Analysis of Traffic Management Logs

Special reporting forms, or logs, were developed for TMC staff use to record variable message sign utilization and traffic signal timing plan modifications. Examples of completed reporting forms are shown in Figures 4 and 5.

2.1.3 Debriefings with Police and Traffic Operations Personnel

Regular debriefings occurred with TMC staff throughout the evaluation to discuss specific traffic incidents and discuss technical and institutional issues. Several of these conversations also included City of Scottsdale Police Department personnel who work closely with the TMC staff. The TMC observations conducted during the Phoenix Open in particular provided an opportunity for extensive discussions with police and traffic operations staff, including real-time debriefing of specific incidents and traffic responses.

Signal Timing Modifications Log

Date	Time	Intersection	Timing Change Made in Response to:	Intent of the Timing Change	Surveillance/Data Collection Method	Time Required to Develop and Implement Change	End Time	Op. Initials
3/10/03	10:30	HAVERHILL	<input checked="" type="checkbox"/> Construction <input type="checkbox"/> Accident <input checked="" type="checkbox"/> Special Event <u>PALEGAWE</u> <input type="checkbox"/> Stalled vehicle <input type="checkbox"/> Periodic update <input checked="" type="checkbox"/> Other <u>PALEGAWE</u>	E/W TRAFFIC BACKUP 10:30 PLAN 4-6, 200 MIN 10:55 6-9, 200 MIN MERGE RT, TRAFFIC, DMS 7	<input checked="" type="checkbox"/> CCTV <input type="checkbox"/> Field observations <input type="checkbox"/> Counts <input type="checkbox"/> Other	15 MIN		DNL
	10:53					5 MIN		
	11:12			11:12 7-9, STOP TIME ED BACKUP, 15 MIN		15 MIN		
	17:31	HAVERHILL	<input type="checkbox"/> Construction <input checked="" type="checkbox"/> Accident <u>RECOVER IN INTERSECTION</u> <input type="checkbox"/> Special Event <input type="checkbox"/> Stalled vehicle <input type="checkbox"/> Periodic update <input type="checkbox"/> Other		<input checked="" type="checkbox"/> CCTV <input type="checkbox"/> Field observations <input type="checkbox"/> Counts <input type="checkbox"/> Other <u>PD RAPID</u>	25 MIN	18:30	DNL
	17:35	" "						
	17:40	HAVERHILL	<input type="checkbox"/> Construction <input type="checkbox"/> Accident <input type="checkbox"/> Special Event <input type="checkbox"/> Stalled vehicle <input type="checkbox"/> Periodic update <input type="checkbox"/> Other	7-9	<input checked="" type="checkbox"/> CCTV <input type="checkbox"/> Field observations <input type="checkbox"/> Counts <input type="checkbox"/> Other	5 MIN	18:30	DNL

End time = time when the signal timing was returned to prior settings (only applicable for temporary modifications; otherwise leave blank)

Figure 4. Example Traffic Signal Timing Plan Modification Log

DMS Operations Log

Date & Time	Sign Location/ID	Message (by page)			Message Posted in Response To:		Duration	Op. Initials
		Page 1	Page 2	Page 3	Type of Event (choose one)	Event Location/Remarks		
1/6/03 10:15 10:17:52	DMS 8 Gro- Reef	Accident Ahead	Merge Left		<input type="checkbox"/> Construction <input checked="" type="checkbox"/> Accident <input type="checkbox"/> Special Event <input type="checkbox"/> Stalled vehicle <input type="checkbox"/> Other	AT P.M. - EB S. Car Rear end Great Advance to the message - All merged left at G.R.	2 1/2 Hours	DL BD
1/6/03 8:20	DMS 3 & 7	Accident at Scottsdale	Avoid Acca		<input type="checkbox"/> Construction <input checked="" type="checkbox"/> Accident <input type="checkbox"/> Special Event <input type="checkbox"/> Stalled vehicle <input type="checkbox"/> Other	slow down & Accident Low Traffic Volume	35 min	BD
1/6/03 8AM -2PM	7	MERGE RIGHT			<input checked="" type="checkbox"/> Construction <input type="checkbox"/> Accident <input type="checkbox"/> Special Event <input type="checkbox"/> Stalled vehicle <input type="checkbox"/> Other	HAYDEN / IND SCHL WB APPROACH LANE RESTRICTION - Advance Warning folks merged	6 HRS	DHL
1/7/03 9-	7	MERGE	>7...		<input checked="" type="checkbox"/> Construction <input type="checkbox"/> Accident <input type="checkbox"/> Special Event <input type="checkbox"/> Stalled vehicle <input type="checkbox"/> Other	11		DHL

Figure 5. Example Variable Message Sign Log

2.2 Strategic Traffic Signal Timing Plan Updates at Individual Intersections

Most of the traffic signal timing changes recorded on the logs described in Section 2.1 were tactical, that is, short-term modifications made in response to incidents, special events, or construction. Strategic timing plan updates—those that modify the basic timing plans in response to changes in prevailing day-to-day traffic conditions—are administered less frequently and constitute a much smaller proportion of the changes captured on the logs. Traditionally, the number of strategic updates that can be performed is severely limited by the labor-intensive nature of the process, which relies upon on-site visual observation of traffic patterns. Visual observations are needed to first confirm the need for a change and identify the type of change that is needed, and then to confirm the effectiveness of the change once it has been made. Given the time consuming nature of this process usually no more than one round of follow-up observation and timing plan refinement can be made. Even given this approach it is not possible to update nearly as many timing plans each year as needed.

A special test was conducted to investigate the benefits of the ITS for strategic traffic signal timing plan updates. As part of the test, the timing plans at two different locations were updated. At the McDowell Road/68th Street intersection the timing plans were updated using traditional “non-ITS” methods, which entail on-scene observation of traffic conditions. The timing plans at the Indian School Road/Goldwater Boulevard intersection were updated remotely from the TMC, with visual observations conducted using the surveillance cameras installed at that intersection. Detailed records were kept of the labor hours associated with both updates. The same staff member conducted both updates. The total labor hours and tasks performed associated with both updates were compared.

2.3 Strategic Traffic Signal Timing Plan Updates Along Corridors

In addition to the signal timing plan updates that are performed at individual signalized intersections, City traffic staff periodically performs coordinated updates of timing plans at a series of signalized intersections along specific corridors. These updates focus on improving the coordination of traffic signals so as to improve progression along the corridor, thus reducing delays and travel times. As part of the evaluation, timing plans along all of the traffic signals along the Indian School Road ITS Corridor (64th Street to Pima Road) were updated. A travel time and delay study was conducted to evaluate the impacts of that update.

The travel time and delay study used the traditional “floating car” technique in which a test vehicle performs multiple runs along the corridor in both directions and in both the morning (7:00-8:00 AM) and evening (5:00-6:00 PM) peak hours. In order to capture the typical travel time, the test vehicle “floats” along the traffic stream at the average travel speed. A Global Positioning System (GPS) unit was utilized that recorded constant, second-by-second data, including latitude, longitude, and instantaneous vehicle speed. Average times are calculated by averaging results for all of the travel time runs for each direction (e.g., eastbound or westbound) or time period (e.g., morning peak hour or evening peak hour).

The “before” data was collected in October 2001 and the after data was collected in February 2003, immediately following the completion of the timing plan updates. All data collection occurred on Tuesdays, Wednesdays and Thursdays, which best reflect typical traffic conditions. Any travel runs that included atypical conditions such as adverse weather or traffic incidents were discarded and redone. A total of six or seven usable runs were obtained in each time period and direction (eastbound and westbound), a typical and satisfactory sample size. The focus of the effort was Indian School Road, but data was also collected for the major parallel roads located to the north (Camelback Road) and south (Thomas Road). The results for the parallel roads provide additional context for interpreting the results for Indian School Road.

2.4 Institutional and Technical Lessons Learned

Through periodic discussions at project meetings, several dedicated “lessons learned” brainstorming conversations, and many conversations with TMC staff and City evaluation team members, a wide range of institutional and technical findings have been assembled. These findings include those pertaining to future ITS deployments as well as future evaluation efforts.

3.0 PROJECT RESULTS

3.1 Tactical Responses to Incidents, Construction, and Special Events

The evaluation confirmed that the Indian School Road traffic management system tools provided TMC staff with the desired capabilities for managing incident, roadway construction and special event traffic, and that the actions taken with these tools did produce the positive impacts on traffic operations that were intended. The findings are based primarily on visual observations on the part of the evaluation team and the TMC staff. Opportunities for collecting traffic data that would quantify these observed benefits were thoroughly investigated, but proved infeasible within the constraints of the evaluation. Chief among the challenges that were faced is the difficulty in effectively mobilizing data collection during these short-term, and in the case of incidents, unpredictable events. The institutional and technical lessons learned discussion in Section 3.4 and the conclusions in Section 4.0 discuss these issues further and provide recommendations.

3.1.1 Incidents

The Indian School ITS proved very useful for coordinating traffic management during traffic incidents, such as accidents, vehicle breakdowns, and spilled loads.

Traffic incidents have profound impacts on traffic operations. Law enforcement personnel respond to traffic incidents. Their responsibilities include both the incident itself (i.e., rescue, investigation, and removal/restore) as well as a certain degree of traffic control and management. The typical traffic control measures provided by the police involve lane closure and setting up detours. The most important objective of such traffic measures is to isolate and prevent vehicles from entering the incident site. From an incident management perspective, this protects the safety of incident responders and prevents possible secondary accidents caused by uninformed, distracted, or confused drivers.

Scottsdale Police Department, like other law enforcement agencies, has developed procedures for implementing temporary traffic control measures in the case of incidents that impede traffic operations. Those procedures are typically implemented by the field police officers and do not require support from the traffic operations.

With the implementation of ITS technologies, new and improved traffic control and management capabilities are enabled. For example, where CCTV cameras are available they allow TMC staff to detect and visualize events (e.g., incidents) as they progress and monitor their traffic impacts both at the incident location and on the surrounding street network. Traffic signal timing can be changed remotely from the TMC to adjust for and accommodate the sudden change in traffic patterns due to the temporary traffic control measures (e.g., closures) implemented by the police. Where signs are available, advisories can be provided on the VMS with the push of a button from the TMC to inform approaching drivers. These ITS-enabled capabilities provide an effective and proactive way to minimize the traffic impacts caused by incidents without burdening the front-line incident responders.

This evaluation intends to investigate and document the benefits of using ITS technologies in assisting incident management. A video camera was placed in the City of Scottsdale TMC. The traffic operators were asked to videotape the entire duration of major incidents, defined as those with significant traffic impact and of significant duration. When the consultant evaluation team was notified of the occurrence of the incident, a meeting with the traffic operators that were on duty during the event was scheduled within days of the incident. The purpose of the meetings was to reconstruct the event sequence during the course of the incident response, aided by the videotape and ITS device operation logs. A time line is used to describe the major decisions and traffic control measures involved in accomplishing the operations.

Case Study: October 10, 2002 Fatal Accident at Indian School/Miller

A motorcyclist southbound on Miller Road was making a right turn onto Indian School Road westbound when an eastbound passenger car on Indian School Road struck him. The accident then caused two southbound cars on Miller Road to collide. The motorcycle driver was fatally injured. The total duration of the incident was 3 hours and 15 minutes, from 10:45 AM to 2:00 PM.

Description of Incident Management Actions

The Scottsdale TMC staff learned of the accident over the police radio scanner at 10:45 AM. The police scanner is a typical source of incident information. At 11:00 AM, police implemented temporary traffic control measures, including:

- Closure and detouring of Indian School Road westbound lanes to 78th Street northbound (east of accident location).
- Closure and detouring of Miller Road northbound at Indian School Road (south of accident location).
- Closure and detouring of Miller Road southbound to 6th Avenue westbound (north of accident location).
- Closure of left turn lane from Indian School Road eastbound at Miller Road (west of accident location).

Figure 6 shows the temporary traffic control measures implemented by the Scottsdale Police Department incident responders.

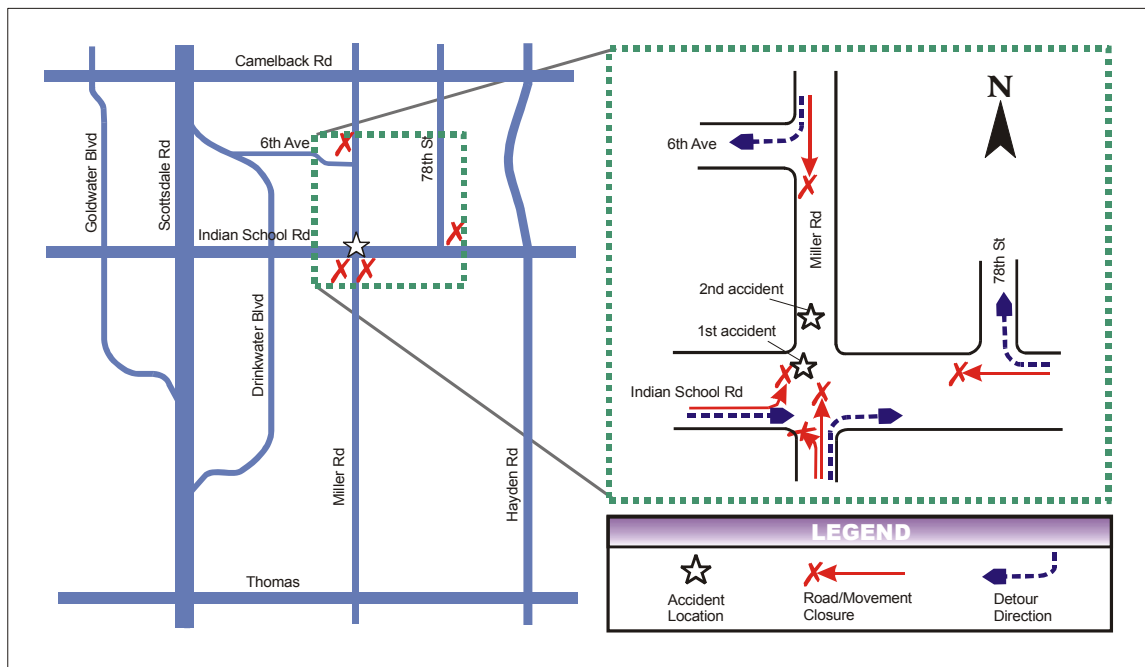


Figure 6. Indian School/Miller Accident Traffic Control Measures

At 10:45 AM, before the police had arrived on scene, the Scottsdale TMC operators used the two nearby CCTV cameras on Indian School Road between Miller Road and Drinkwater Boulevard, and between Hayden Road and 82nd Street, to verify the incident location and the traffic impacts. At 11:00 AM, police notified the TMC of the road closures and estimated duration. With the help of camera images, the TMC operators were able to develop and implement a preliminary traffic signal timing plan at the time police implemented the closures and detours. The preliminary signal timing plan focused on the accident intersection (Indian School and Miller) to accommodate the lane closures and increased traffic volume onto Indian School Road eastbound due to the detours. In addition, the signal coordination along the Indian School Road corridor was set to “free operation” (i.e., none coordinated), due to the disruption of traffic at Miller Road. The TMC operators continuously monitored the traffic flows at the accident intersection and provided the road closure information on three VMS around the affected area.

At 11:30 AM, with traffic well managed in the immediate incident scene, TMC staff began to investigate conditions at adjacent intersections that may have been impacted by either the incident or the response measures. Due to the lack of CCTV camera coverage, it was necessary to dispatch a technician to investigate a number of those intersections, including Thomas/Miller, Miller/Camelback, Camelback/Scottsdale. Based on limited observation by the technician, at 11:45 AM (60 minutes after the detection of the incident), secondary signal timing plan changes were applied to a number of intersections, including Miller/Camelback and Camelback/Scottsdale.

For the remainder of the incident duration, periodic adjustments were made to the accident intersection and the adjacent intersections where CCTV coverage is available. The incident management event sequence is presented in Figure 7.

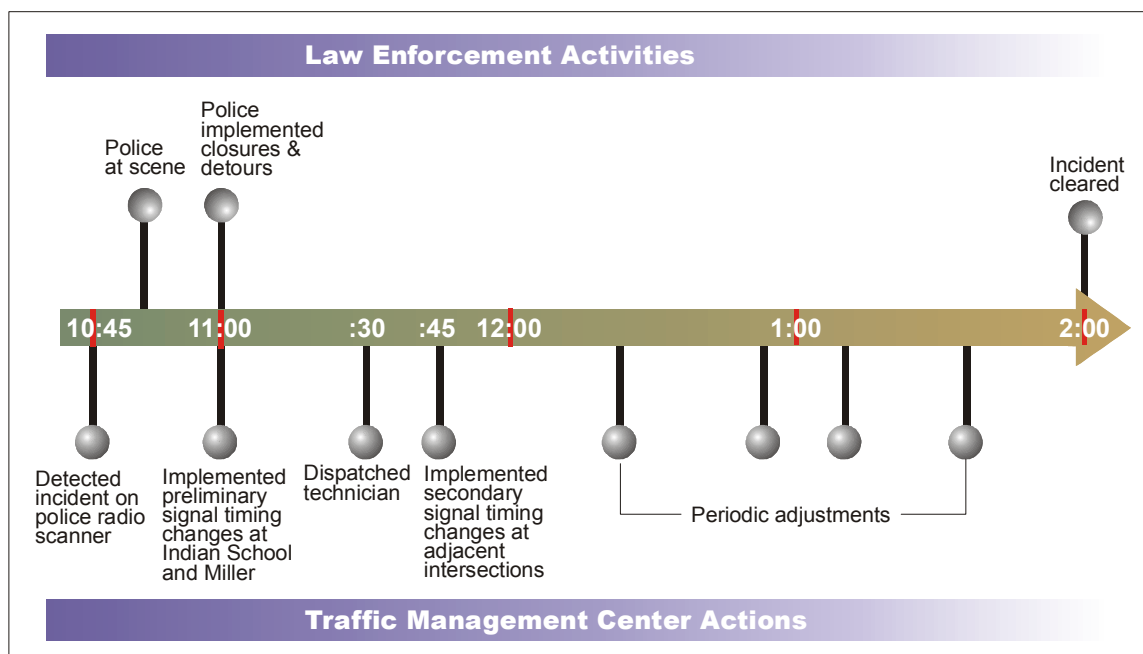


Figure 7. Indian School/Miller Accident Incident Management Timeline

Assessment of ITS Impacts

Early Detection and Validation Using CCTV

The early detection and verification of the incident allows traffic operators to quickly understand the situations at and around the incident location and develop and implement traffic control measures to minimize the traffic impacts. In this case, the proactive use of the police radio scanner and CCTV cameras significantly shortened the time needed to devise a preliminary signal timing plan. The plan was implemented as soon as the police notified the TMC of the closures and detours, just 15 minutes after the detection of the incident. This early action was critical in minimizing the initial chaos typically observed at the scene during the first hour of the occurrence of a major traffic incident.

Effective Traffic Management Using ITS tools

This case study demonstrated that ITS technologies are useful in minimizing the traffic impacts caused by the incidents. For example, traffic signal timing was adjusted to eliminate or minimize the signal phases that permit the traffic to enter the closed roadway. The phases that lead the traffic to the planned detour are lengthened to accommodate the increased traffic volumes due to the diversion. The CCTV cameras provide the ability to continuously monitor the conditions and to determine the effectiveness of the periodic signal timing changes.

Future Improvements

It was evident in this case study that the lack of CCTV cameras on the cross streets and other parallel arterials to Indian School Road resulted in significantly more time and efforts to develop and implement the secondary traffic signal timing changes at adjacent

intersections. Arguably, the technician's recommendations of action can be unreliable due to the limited observation time and the inability to concurrently observe the conditions on adjacent approaches. Furthermore, it is costly and thus infeasible to obtain multiple follow-up observations/verifications using the field technician. This situation, however, is expected to be improved in the future as the City deploys more CCTV cameras as outlined in the Five-Year Capital Improvement Program.

Institutional Coordination Between Traffic Operations and Police

In current incident response procedure, the on-scene emergency responders typically devise road closure and traffic diversion plans without actively seeking inputs from the traffic operations. The TMC is usually notified only after the temporary traffic management strategy has been developed by the responders and is being implemented by them. In the future, with expanded CCTV coverage and improved traffic management capability, it is conceivable that procedures may be enhanced to better integrate the TMC and ITS capabilities and strategies into the traditional incident detection, verification, response and management process. However, such integration requires changes in organizational culture for both law enforcement and traffic operations. These changes will require time. In past years, traffic operations staff has had continuous and successful coordination with the police on various issues of common interest, including the special event management, safety, etc. In the future, as Scottsdale expands its ITS capabilities it is important that this positive working relationship be maintained and expanded.

Variable Message Sign Utilization In Support of Incidents

Over the course of the approximately six-month long evaluation period, the six variable message signs in the Indian School Road corridor were utilized on numerous occasions to post incident-related messages. During this period, a total of 28 such messages were posted. The duration of the messages varied from 30 minutes to several hours. Message content included advisories to proceed with caution, to avoid areas, notice of road closures and lane restrictions, and notification that workers are in the roadway. Example messages include:

- "Severe accident at Hayden/Indian School, avoid area"
- "Vehicle fire, road closed at 75th Street"
- "Incident at 75th Street, workers present, use caution"
- "Accident ahead, merge left"
- "Accident at 96th and Shea, avoid area"
- "Accident at Goldwater, two lanes blocked"
- "Accident ahead at Goldwater, no thru traffic"
- "Accident at Miller, expect delays"
- "Incident ahead, use caution"

TMC staff reported that in many instances there was a visible change in traffic patterns—observed using the CCTV cameras—in response to messages advising motorists to merge left or right.

Traffic Signal Timing Plan Modifications in Support of Incidents

A sample of detailed, comprehensive logs of all traffic signal timing plan modifications for the period March 12 – February 13, 2003 were analyzed. This period included 22 workdays (days when the TMC was staffed).

A total of 67 traffic signal timing plan modifications were made during the 22-day analysis period. That frequency amounts to 393 modifications per TMC work year (254 days). The 22-day analysis period does include an intensive period of construction activity at Indian School/Hayden, but does not include the approximately ten days of the Barrett-Jackson Auto Auction and Phoenix Open golf tournament, when the TMC is staffed 7-days per week and when many traffic signal timing plan modifications are made. Most of the modifications relied on information obtained using the CCTV cameras.

Nine (9) percent of the 67 traffic signal timing plan modifications that occurred during the 22-day analysis period were made in response to a traffic incident, either an accident or a stalled vehicle, or weather conditions (heavy rain, flooding). (The other 91 percent of the timing plan modifications are discussed in later sections). Typically, in the case of a traffic incident, additional green time was provided to those traffic movements that were most severely impacted by the incident. In some cases manual signal control was utilized to assist with traffic control. Incidents that were addressed in this manner include:

- Rollover accident at Indian School/Hayden
- Stalled vehicle at Indian School/Drinkwater
- Flooding at Hayden/McDonald
- Flooding at Hayden/Osborn
- Rain delays at Hayden/Indian School
- Stalled vehicle at Pima/Frank Lloyd Wright

3.1.2 Construction

The seven-month long, major reconstruction of the Indian School/Hayden intersection proved both a challenge and an opportunity for this evaluation. Initial plans to analyze traffic patterns with and without construction advisory messages on permanent and temporary portable variable message signs proved infeasible. City policy dictated that messages be posted in advance of the construction, thus eliminating the opportunity to compare traffic patterns during construction under “with message” and “without message” scenarios.

The evaluation included interviews with TMC staff, analysis of the VMS and traffic signal timing logs, and review of videotapes of traffic during construction. Based on these activities it is apparent that:

1. The Indian School ITS provided staff with the desired traffic management capabilities.
2. ITS traffic management capabilities were exercised vigorously.
3. Based on TMC staff visual observation, the ITS traffic management strategies did promote traffic flow through the construction area.

CCTV Camera Utilization in Support of Construction

The CCTV cameras located in the vicinity of the Indian School/Hayden intersection provided the primary means of traffic observation for TMC staff. The cameras were used continuously over the course of the reconstruction. The traffic signal timing logs maintained by TMC staff indicate that nearly all of the timing changes were made proactively, based on information that the TMC staff obtained using the cameras.

Variable Message Sign Utilization in Support of Construction

A total of 41 construction-related messages were posted by TMC staff on the six permanent variable message signs located on Indian School Road over the period September 1, 2002 – March 12, 2003, an average of over six messages per month. These messages accounted for approximately 48% of the messages posted during this period. About half of these messages were related to the construction at Indian School/Hayden. Message content included advisories to merge left or right, to expect delays, and the start and end times of construction activities. Example messages include:

- “Paving through 3/1/3, long delays expected, Hayden/Indian School”
- “Right lane closures possible at 64th St thru 4/4”
- “Roadwork through 4/4, stay left”
- “Expect right lane closures, 64th St.-56th St., day/night through 4-24”
- “Westbound Indian School at Hayden, closed 9-11 pm tonight”

Traffic Signal Timing Plan Modifications in Support of Construction

Fifteen (15) percent of the 67 traffic signal modifications that were recorded during the 22-day period that was studied were made in support of roadway construction or maintenance activities. Additional green time was provided to movements most impacted by construction delays and to those movements that support traffic detour strategies. Most of these modifications relied on information obtained using the CCTV cameras.

3.1.3 Special Events

Barrett-Jackson Auto Auction/Phoenix Open Golf Tournament Case Study

Two major special events that occur each year in Scottsdale over the course of a single week in January provide an excellent opportunity to observe the benefits of ITS for managing event traffic. The Phoenix Open Professional Golf Association (PGA) Tournament is held each year at the Tournament Players Course located along Frank Lloyd Wright Boulevard just west of the Loop 101 Pima Freeway. The internationally known Barrett-Jackson auto auction is held at WestWorld, located in the same vicinity. These events attract a very large number of spectators annually and place demands on the roadway system that far exceed those of a typical day.

The 2003 Barrett-Jackson auction held January 15-19, 2003, drew approximately 165,000 spectators. The 2003 Open, which occurred the week of January 20 – 26, 2003, drew approximately 477,000 spectators. These events provided an excellent

opportunity for the evaluation team to observe firsthand and document the benefits of the Scottsdale's advanced traffic management system. Although traffic management for the Open did not rely significantly on the equipment on Indian School Road, several of the same technologies and techniques were utilized in the vicinity of the tournament. These technologies include CCTV cameras to observe traffic conditions, the centralized traffic signal control system that allows remote modifications to traffic signals, and the Traffic Management Center, which provides a focal point for command and control.

During the Barrett-Jackson and Open events, one or more representatives of the City of Scottsdale Police Department's Accident Investigations Traffic Enforcement Division were stationed at the TMC. That officer coordinated with traffic control officers stationed at parking lots and intersections surrounding the tournament site via radio. Also supporting the special event traffic management were one of the City's traffic signal technicians (who is stationed at the TMC more or less full time during weekday business hours during this period) and the City traffic personnel with offices adjacent to the TMC (who provide intermittent support during this period).



**Figure 8. TMC Video Display for the Phoenix Open/
Barrett-Jackson Auto Auction Area**

Members of the evaluation team spent approximately 12 hours in the TMC during the Open, observing operations and interviewing City traffic and law enforcement personnel. The benefits of the traffic management system were clear, and can be categorized into two main types:

1. Labor savings for law enforcement.
2. More effective traffic control.

Law Enforcement Labor Savings

According to Detective Paul Thompson, the primary Police Department TMC operator during the 2003 Barrett-Jackson auction and Phoenix Open, a single police officer in the TMC, with CCTV cameras at their disposal and with the capability of quickly and easily making timing plan modifications to any or all of the area traffic signals, can take the place of several traffic control officers in the field. Without the TMC, two officers are typically stationed at each traffic signal, one to monitor traffic and for on-site traffic control, and the other to manually implement traffic signal timing changes via the traffic signal controller cabinet located curbside. With an officer at the TMC, the officer making timing changes is not needed. An officer located at the TMC, or TMC traffic operations staff, make those changes.

In past years, between 50 and 55 officers have been deployed for traffic control for the Barrett-Jackson/Open on a typical day. In 2003, with a full-time officer at the TMC, only 24 officers in the field were deployed on a typical day, a savings of between 26 and 31 field officers per day. These figures are shown in Table 2.

Table 2
Phoenix Open/Barrett-Jackson Daily Law Enforcement Labor Comparisons

Without ITS	With ITS	Labor Savings Per Day
50-55 Field Officers	24 Field Officers; 1 Officer in TMC	25-30 Field Officers

More Effective Traffic Control

The City's advanced traffic management center, coupled with a police officer in the TMC, greatly increases the ability to adapt traffic signal timing to constantly changing traffic conditions during special events and incidents. By reassigning unneeded green time from less congested traffic movements to more congested traffic movements, average delay to motorists and overall delay can be reduced. "Worst case" conditions are those where all movements require more green time than is available. Even under these conditions the ability to adjust green time during each signal cycle, based on the specific traffic volumes on each approach during that particular cycle, insures that delays are spread more equitably across all the approaches. This helps ease driver frustration.

The improved traffic management ability associated with the TMC and the advanced traffic management tools is a product of the following:

- A. Elimination of the **lag time** between notification and intervention (i.e., changing the traffic signal timing).

- B. Improved **surveillance accuracy** and **information interpretation**.
- C. Decision-making based on an **area-wide, coordinated perspective**, rather than a localized, uncoordinated perspective.

A. Elimination of Lag Time

CCTV cameras eliminate the lag time that occurs when TMC operators rely upon field observers for traffic observations. This allows changes to be made more quickly and eliminates traffic delay that would otherwise occur. Without cameras, the TMC operators are not aware of a problem until contacted by one of the field officers. After ascertaining the nature of the problem, a process that can take a few minutes, the TMC operator implements a modification. Then, after a few more minutes, the officer provides another traffic observation. The TMC operator must interpret that information, subject to “miscommunication”, and decide to:

1. keep the modification in place,
2. fine-tune the modification, or
3. return the signal to its original timing, such as when it appears that the situation cannot be improved.

This process is repeated each time traffic patterns change significantly, which can be quite frequently due to short term peaks in ingress and egress traffic volumes. The time lags inherent in each link in the field-to-TMC-to-field communication link add up. When CCTV cameras rather than field observers are used these time lags are eliminated. The TMC operators are able to see for themselves what is happening in real-time. Coupled with the remote control made possible through the centralized signal system, they can implement timing changes quickly. Figure 9 compares these processes graphically.

It should also be noted that according to TMC operators about half of the “problems” that they identified are at non-staffed locations, identified solely through the CCTV cameras. In those cases the cameras reduce even more traffic delay because they do not just speed up the implementation of timing plan change but allow for a modification to be made that otherwise would not be made at all.

B. Improved Surveillance Accuracy and Information Interpretation

CCTV cameras also improve the accuracy of surveillance, thus eliminating the indecision and poorly informed decisions that are possible when TMC operators rely on information from field observers. The level of experience in on-site traffic management varies widely among the field observers. Even police officers or other City personnel with traffic experience do not have the specialized traffic signal experience of the TMC staff. As a result, the information relayed to the TMC is not as useful as the first-hand observations of the TMC staff who develop and implement timing plan modifications.

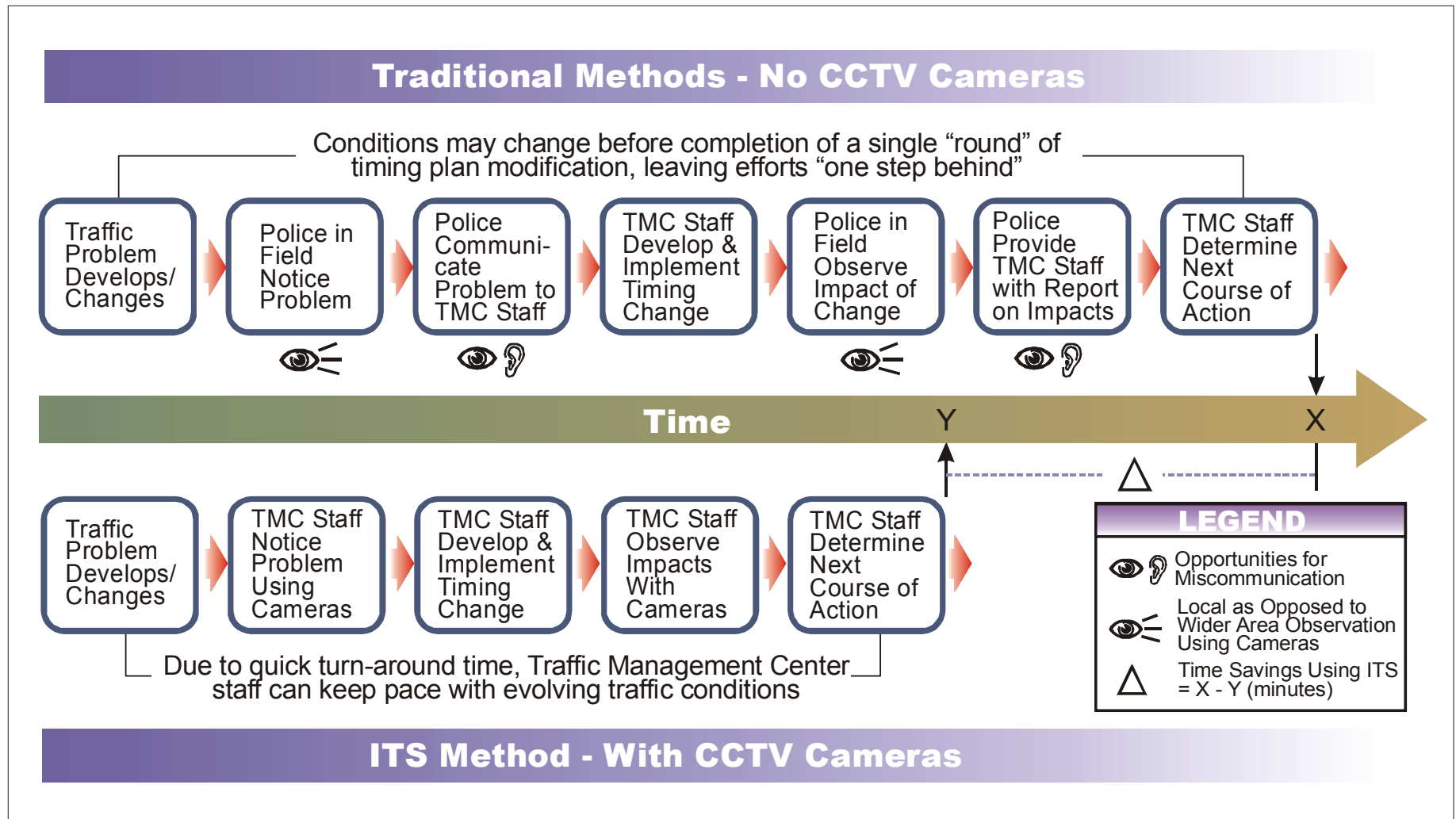


Figure 9. Elimination of Time Lags in Tactical Signal Timing Modifications

Both police and traffic personnel operating the TMC reported that “false alarms” or overstated reports are especially common. These are cases where the field observer may find a particular traffic condition to be problematic and warranting a timing plan change. However, the TMC personnel may recognize the condition as one that cannot be improved without causing worse problems elsewhere. The potential for over-stating the need for intervention and the appropriate magnitude of the intervention further threaten effective communication when combined with these additional factors:

- Mix-ups with street names.
- Imprecise estimates of distances and vehicle queue lengths.
- Occasional confusion over directions (i.e., north, south, east, west) and spatial relationships (e.g., “on the left”, “on the right”).

This confusing and sometimes inaccurate information from the field can lead an otherwise uninformed TMC operator (lacking camera information) to make changes that may exasperate the problem.

C. Decisions based on Area-Wide, Coordinated Perspectives

The TMC provides a focal point for area-wide command and control. The TMC and its operators, who are able to see the big picture and have specialized traffic control experience, can be seen as the “central nervous system” of the overall traffic management effort. They process a variety of inputs and then identify and implement counter measures in a coordinated fashion. By consolidating information in one location, decisions can be made based on an area-wide and coordinated perspective rather than a localized, uncoordinated one. Traffic conditions are highly interdependent, especially when the roads are at capacity: impacts at one location trigger a chain reaction of impacts at adjacent locations, like ripples in a pond. When decisions are made based only on what is visible from the ground at one location—which is the case without the ITS tools—any local improvements may be offset by even greater deteriorations elsewhere.

The disadvantages of traditional event traffic control (i.e., without cameras at the TMC and central control and coordination) significantly impair traffic management effectiveness. During large special events traffic volumes are very high and in flux. Under these conditions, time lags, inaccurate or incomplete information, and the lack of a big picture perspective, increase the probability that the wrong changes may be made and/or the right changes may be made too late to do any good. By the time the “right” action has been taken, traffic conditions can easily have changed enough to make it the wrong action, one that may only compound traffic congestion and delay. CCTV cameras and the ability to change traffic signal timing plans remotely allow TMC operators to see first hand and in real-time what is happening throughout an entire area and to very quickly implement changes that will improve traffic conditions.

The evaluation team was able to observe these benefits directly during their visits to the TMC during the Phoenix Open. Over the course of many hours of observation, the evaluators were able to observe TMC operators identifying traffic back-ups using CCTV cameras, validating field reports using the cameras, implementing timing plan changes, monitoring the impacts of those changes using the cameras, fine-tuning the changes and returning the signals to the original settings when warranted. Nearly all of the disadvantages associated with the non-technology approach (i.e., no cameras) were also directly observed as the TMC operators dealt with locations lacking cameras. In

these cases the time lag and miscommunication issues identified by the TMC operators were evident.

“Hot Spot” Example: Frank Lloyd Wright Boulevard/Loop 101 Freeway

TMC operators dealt with a number of recurring “hot spot” intersections during the time that the evaluation team observed operations during the Phoenix Open. Friday afternoon is a traditionally high traffic volume period at the Open as many spectators who arrived in the morning or early afternoon are leaving and as late afternoon spectators and attendees of evening social events are arriving.

Late in the afternoon on Friday, January 24, 2003, the TMC staff operators noticed very long westbound and southbound traffic queues building at the intersection of the Loop 101 Freeway Frontage Road and Frank Lloyd Wright Boulevard. They observed the traffic using the zoom capabilities of the CCTV camera located west of that location at the Frank Lloyd Wright/Hayden intersection, as shown in Figure 10. The TMC operators implemented one of the pre-defined “non standard” timing plans that have been developed in advance by City traffic engineers and which favor a certain combination of movements that fit the pattern of what the TMC operators were observing.

Shortly after implementing the timing plan change the TMC operators were able to visually confirm its effectiveness, as southbound and eastbound queue lengths were markedly reduced. As time progressed, queue lengths for other directions would sometimes begin to build and the operators were able to equalize queues by reducing the amount of additional green time provided to southbound and eastbound movements, or by reverting to the original, more balanced timing plan. As time passed, and as waves of traffic came and went, queue lengths for southbound and eastbound traffic again grew long. The TMC operators then repeated the preceding process. No officers were stationed at this intersection, which is at the far southeastern corner of the Phoenix Open traffic control area, and lacking the TMC the CCTV cameras and the skill and experience of the operators, motorists would have experienced additional delay.

Variable Message Sign Utilization

Between September 1, 2002 and March 12, 2003, TMC staff posted a total of 12 special event-related messages on the six (6) permanent variable message signs located on Indian School Road. The messages accounted for approximately 14% of the messages posted during this period. These messages pertained to Cactus League baseball parking and the Parada Del Sol.

TCM staff utilized
CCTV camera at Hayden/
Frank Lloyd Wright Blvd. to
observe conditions and
manually adjusted traffic
signal timing in real-time
to balance heavy
southbound and eastbound
traffic flows at FLW/101
Frontage Road.

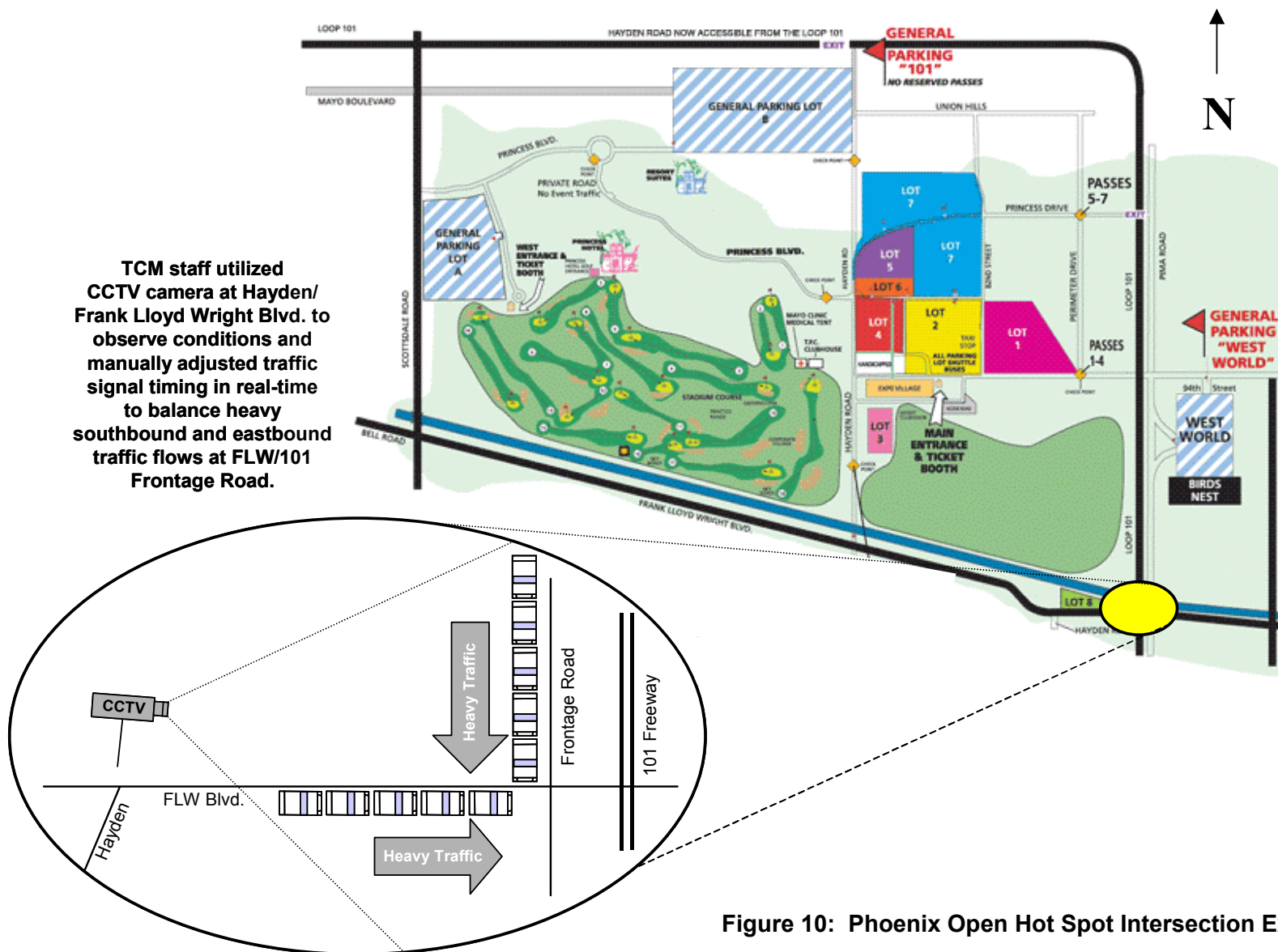


Figure 10: Phoenix Open Hot Spot Intersection Example

3.2 Strategic Traffic Signal Timing Plan Updates at Individual Intersections

This analysis indicates that the use of surveillance cameras for remote observation of traffic conditions result in both labor savings and allows for additional refinement of signal timing plans relative to the non-ITS approach that uses on-site observations. These additional refinements are expected to further reduce delays. As a result, a timing plan update using camera observations can be performed more quickly and more effectively.

Table 3 presents the results of this analysis. The initial retiming—observation, followed by timing adjustments, followed by additional observation—required only 35 minutes for the Indian School/Goldwater intersection when surveillance cameras were used from the TMC to observe traffic. This same process using on-site observations that included travel to and from the intersection (3 miles one way) required 135 minutes at the 68th/McDowell intersection. Two additional rounds of observation and adjustment were performed at the Indian School/Goldwater location, both of which yielded additional improvements in intersection operations (based on visual inspection). The total time required to perform three complete rounds of timing plan modification was 90 minutes for Indian School/Goldwater, compared to 135 minutes for a single round of modifications at 68th/McDowell. ITS provided a total time savings of 45 minutes.

These results indicate that given the same total labor resources, 2.1 times as many intersection timing plan modifications can be performed using ITS. Further, since additional refinements are possible, the ITS-enabled updates are likely to be more effective.

City traffic staff reports that currently, using field observation techniques, they are able to perform no more than about 45 updates each year. If surveillance cameras were available at all of the locations where updates are required, this analysis indicates that this number could be increased to approximately 95 updates each year.

Table 3
Labor Savings Comparison for Individual Intersection Strategic Timing Plan Updates

Indian School/Goldwater – With ITS (Remote observation of traffic conditions using CCTV cameras)						68 th /McDowell – Without ITS (On-site observation of traffic conditions)					
Round	Activity	Description	Start Time	End Time	Total Time (min)	Round	Activity	Description	Start Time	End Time	Total Time (min)
1	Observe	Observed Indian School/Goldwater and surrounding intersection with cameras from TMC.	15:45	16:05	20	1	Observe	Travel to 68 th /McDowell (3 miles). Observe intersection; note that e/w left turn does not always clear. Return to TMC.	13:30	14:30	60
	Adjust Timing	Observed SB left turn does not always clear; adjusted timing.	16:05	16:15	10		Adjust Timing	Adjust timing sheet and signal timing to increase e/w left turn arrow green time.	14:30	14:45	15
	Observe	Observe effect of timing plan changes using cameras from TMC. Noted improvement.	16:15	16:20	5		Observe	Travel to 68 th /McDowell. Observe intersection. Noted improvement. Return to TMC.	14:45	15:45	60
Subtotal					35	Subtotal					135
2	Adjust	Further adjustment of timings.	16:20	16:25	5						
	Observe	Additional observation using cameras. Discovered n/s thru was in coordination max. recall.	16:25	16:45	20						
Subtotal					25	Subtotal					
3	Adjust	Put n/s in min. recall. Noted additional improvement.	16:45	16:50	5						
Subtotal					5	Subtotal					
Grand Total					65	Grand Total					135


Total time savings using ITS = 45 minutes


3.3 Strategic Traffic Signal Timing Plan Updates Along Corridors

Corridor traffic flow was effectively improved by traffic signal timing plan updates, as supported by the travel time and delay study conducted on Indian School Road before and after implementation of the ITS system. Figure 9 (page 28) summarized the before-after travel time impacts. Segmentation of Indian School Road into eastern and western segments was necessary in order to insure that any impacts related to the Hayden intersection reconstruction were not intermixed with impacts related to the traffic signal timing plan update. The travel times shown in Figure 9 do not include times on the links approaching the Hayden Road intersection.

Figure 11 on the following page presents the travel time changes (post-ITS deployment versus pre-ITS deployment) for the four analysis periods: eastbound AM, eastbound PM, westbound AM and westbound PM. The differences shown in Figure 11 are changes in *average* travel times (results are averaged over six or seven travel runs in each direction and time period). For example, average eastbound PM travel times were reduced by 64 seconds. The objective, of course, is to reduce average travel times. The relative sizes of the “traffic volume” arrows in Figure 11 identify in which direction traffic volumes are heaviest in each analysis period. 24-hour traffic counts collected during the travel time data collection periods indicate that during the morning peak period (7 – 8 AM), over most of the corridor, about 70% of the total traffic is moving westbound. During the evening peak period (5 – 6 PM), the pattern is reversed, with eastbound traffic accounting for approximately 65% of total traffic. It is especially important to reduce times in the peak traffic direction, since a larger number of vehicles are impacted. In this project, travel time reductions were achieved for the predominant traffic movements in both the morning and evening periods. Table 4 summarizes the travel time results. The cause of the variation in travel time impacts across the four analysis periods is not clear.

Table 4
Travel Time Comparisons

Analysis Period	Change in Average Travel Time Over 3-mile Corridor	% Change
Eastbound AM	+17 seconds	+ 5%
Westbound AM	- 4 seconds	- 1%
Eastbound PM	- 18 seconds	-4%
Westbound PM	- 64 seconds	- 15%

 = peak traffic direction (traffic volumes are higher in this direction than in the opposite direction during the given time period, i.e., AM or PM)

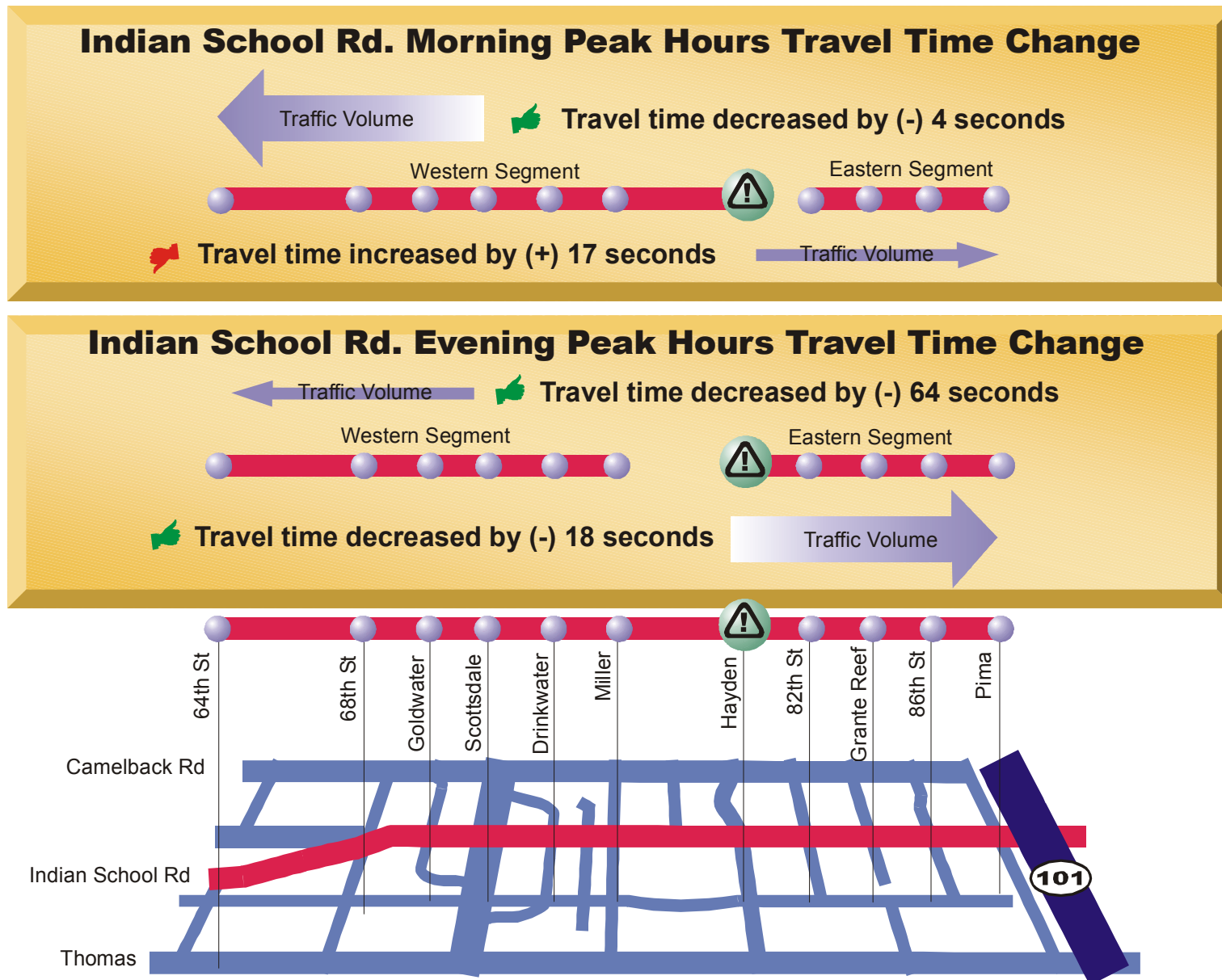


Figure 11. Indian School Road Travel Time Results

In addition to travel times, two intersection specific measures were collected: probability of a stop and average stop duration. For this analysis, a stop was defined as anytime the test vehicle fell below 5 mph, as measured automatically by the GPS device. The probability of a stop is based on the percentage of runs where a stop occurred at the intersection. For example, a 70 percent probability of a stop means that on 7 out of 10 travel time runs, the test vehicle had to stop. As indicated in Table 5, both intersection delay-related measures improved after implementation of the corridor traffic signal timing plan update. The overall average probability of a stop (at any given intersection) decreased by 5%. Average stop duration decreased by 7%.

Table 5
Intersection Performance Measures: Before vs. After Changes

Intersection	Probability of a Stop			Average Stop Duration (Sec.)		
	Before (Oct. 2001)	After (Feb. 2003)	Change	Before (Oct. 2001)	After (Feb. 2003)	Change
64th St	0%	0%	0%	0	0	0%
68th St	70%	18%	-52%	20	15	-22%
Goldwater	72%	71%	-1%	42	44	5%
Marshall Way	0%	11%	11%	0	10	
Scottsdale	46%	48%	2%	44	13	-71%
Buckboard	29%	25%	-4%	16	10	-40%
Civic Center	66%	67%	1%	30	48	59%
75th St	4%	4%	0%	3	3	18%
Miller	48%	23%	-25%	28	22	-21%
Hayden						
82nd St	16%	0%	-16%	9	0	-100%
Granite Reef	0%	4%	4%	0	2	
Pima Rd	0%	15%	15%	0	11	
Corridor Average	29%	24%	-5%	16	15	-7%

Note: Data was not included for the Hayden Road intersection because it was reconstructed during the evaluation. It would have been impossible to differentiate ITS impacts from impacts associated with the reconstruction.

The strategic corridor traffic signal timing plan updates were performed based primarily on on-site visual observations by the TMC staff, who are still developing techniques for using CCTV cameras to support corridor timing plan updates. TMC staff expects that in the future CCTV cameras will allow some or even all of the field observations to be eliminated.

3.4 Institutional and Technical Lessons Learned

Based on a series of discussions with the City's evaluation team, including TMC staff, lessons learned have been identified in three areas:

1. Technologies
2. Operations
3. Deployment Strategy

Lessons learned in each of these areas are summarized in the sections below.

3.4.1 Technologies

CCTV Cameras

The performance of the closed-circuit television surveillance cameras exceeded expectations. The image quality and pan-tilt-zoom speed of the Indian School Road cameras is noticeably superior to the earlier generation cameras that are installed elsewhere in the City.

The evaluation experience confirms the validity of the City's established CCTV deployment standard of installing cameras at major-major and major-minor arterials (1 mile roads and ½-mile roads). Such spacing provides adequate coverage. No problems were experienced with the signal pole mounting approach that was chosen over the approach of mounting the cameras on separate poles. The camera lenses do become dirty and require periodic cleaning once every 3-6 months and after rainstorms. This work is currently being done by the City signal crew under an informal relationship with the ITS staff. This approach should probably be formalized in the future as additional cameras are added. Fiber optic communications for CCTV proved effective. Experience with CCTV units supported by T1 (high speed phone line) communications has also been positive. Most camera maintenance can be performed by the ITS staff.

Radar Traffic Detectors

Radar traffic detectors were evaluated as a potential substitute for the inductive loops, the traditional technology for detecting traffic for traffic signal control. Loops are installed with saw-cuts in the pavement surface. Although loops are relatively inexpensive and are a proven, familiar technology, they require routine maintenance that entails traffic disruptions and exposure of workers to road hazards. Radar traffic detectors are mounted above the roadway on signal poles or separate structures and can be maintained without disrupting traffic.

The Indian School Road experience with radar traffic detectors indicates that they are not a viable alternative to loops. When installed atop the signal poles, it was not possible to achieve both the desired width and depth of detector beam coverage. Within the area that the detectors could cover, they performed well and TMC staff believes they represent an excellent choice for mid-block traffic counting where there will space constraints will not impinge on their effectiveness. ITS staff plans to relocate the existing radar detectors to mid-block locations for this purpose.

Video Traffic Detectors

Video traffic detectors were also evaluated as a potential substitute for inductive loop traffic detectors at signalized intersections. In addition to providing the same maintenance benefits as radar detectors, that is they are mounted above ground on the existing signal poles and can be maintained without disrupting traffic or endangering workers, they provide a potential added benefit. The video image that is utilized by the detectors to detect vehicles is also made available for display in the TMC, much like the CCTV image. Although their performance must still be judged primarily based on traffic detection capability, the video image is a potential bonus and would in effect extend surveillance coverage.

The Indian School Road project experience indicates that current state-of-the-art video traffic detectors are not an attractive alternative to loops. The performance of the units as video detectors proved unacceptable due to reliability issues. East-west image recognition accuracy was especially bad due to sun travel. Even after calibration, the cameras had difficulty recognizing black, gray and red cars due to sun glare, especially at dusk. They also registered false vehicle detections based on tree shadows and other optical effects.

The video surveillance capability of the cameras was far less useful than anticipated. Unlike the CCTV cameras, the video detectors are calibrated based on an exact camera position and require recalibration after they've been moved. As a result, video detection offers only a fixed-position image with no zoom capability. Unable to zoom out or pan from left to right or up and down, the cameras provided a very limited viewing area and were not very useful for TMC surveillance. However, video detection should be given additional consideration in the future as performance improves, the technology matures, and costs fall.

Based on the experience with radar and video detection, traditional inductive loops continue to be the preferred technology for vehicle detection for traffic signal control. However, efforts should continue to identify a satisfactory replacement technology that eliminates in-street maintenance.

Variable Message Signs

The variable message signs performed as intended. The evaluation considered such factors as VMS placement, spacing and CCTV supplementation.

The placement of some of the signs is not ideal. Some signs are not located as far in advance of logical diversion points as is desirable. By the time that a motorist is able to view and absorb a message, they may not always have the opportunity to turn off. A sign is needed for westbound traffic, just west of Pima, to facilitate detours onto Granite Reef. The VMS facing westbound traffic just east of Miller Road is too close to Miller Road. Also, more signs are needed on the western end of the Indian School corridor and the signs on the eastern end are probably too closely spaced. Future VMS location decisions should carefully consider alternate routes strategies. Development of a City-wide VMS plan would help guide VMS decision-making on individual projects.

In addition to spacing considerations, VMS placement should take into account CCTV coverage. It is important to visually verify conditions before posting a message. The sign itself need not be visible, but cameras should be available to view the area to which the message refers.

3.4.2 Operations

The Indian School ITS experience confirms the vital role that CCTV cameras play in the overall traffic management strategy. The cameras are indispensable. They provide the basic information and feedback that underlies any successful traffic management intervention, whether that be a modification to a traffic signal timing plan, posting of a message on a variable message sign, relaying vital information to law enforcement, etc. Seventy-eight (78) percent of the traffic signal timing plan modifications documented on the logs maintained by TMC staff were proactive changes, made in response to

information obtained by the staff. Only 8 percent of the changes were reactive—that is, changes made based on citizen, other City staff, or law enforcement notifications.

The current configuration of the video display wall in the TMC and the CCTV viewing strategy is performing satisfactorily. However, a second TMC operator will be needed as the number of cameras increases. The TMC staff plans to electronically partition the video display into two main areas to accommodate the increases in camera numbers. One area will be utilized by one of the operators for dealing with specific situations. The second operator who will be responsible for reviewing an automatically scrolling “tour” of CCTV views will use the other area. In the long run, it will be desirable to monitor the ITS industry’s development of automatic CCTV monitoring capabilities which alert operators only when needed. Even when images are set up to scroll automatically, there is a practical limit to how many cameras can be monitored by an individual.

The combination of video surveillance, remote monitoring, and signal timing modification capabilities of the City’s centralized traffic signal control system proved even more effective than was anticipated. As evidenced by the signal modification logs, many modifications were made and essentially all of them relied on CCTV information. CCTV has proven effective in supporting individual intersection timing plan modifications. With some additional experimentation, it is expected that CCTV may reduce or even eliminate the need for field observations to support corridor traffic signal timing exercises.

The ability to respond real-time to public complaints regarding traffic signal performance in progress has enabled the TMC staff to be much more responsive. In some cases, staff is able to use a camera to observe a situation and implement a change as they are talking to the caller on the phone. TMC staff characterizes attempting to modify traffic signal timing plans without the immediate visual verification of impacts as “a shot in the dark”. The cameras provide for immediate and definitive feedback. Camera usage has driven home the point to staff that sometimes additional timing plan changes do not improve traffic conditions. Without visual observation of the impact of changes it is more likely that non-productive changes are implemented. CCTV and the central traffic signal control system have also eliminated the long lag time between identification of a problem, development of a solution, implementation of the solution, and observation and refinement of the solution. Without the ability to quickly verify conditions, this process may extend to the point where the original condition that was to be addressed has changed. This can lead to wasted efforts.

The Indian School Road ITS implementation and previous experience with two permanent variable message signs located in north Scottsdale have taught the TMC staff a lot about effective message posting. Staff has a better appreciation of the need to keep messages short and concise so that they can be quickly read and understood by travelers. Although the impact of the signs on the traveling public could not be fully explored given the resource constraints on this evaluation, visual observations by TMC staff indicate that signs are very effective in facilitating smoother, safer lane merges.

The ability to actively orchestrate traffic diversions and to provide motorists with all of the information they need to make their own alternate route choices will be enhanced as additional CCTV cameras and VMS are implemented. The current Indian School Road system is quite useful for incidents on Indian School Road. However, there is insufficient information on parallel routes to support an aggressive, day-to-day traveler

information dissemination strategy. That is, to provide travelers with up-to-the-minute recommendations on route selection under normal rush hour conditions.

The Indian School ITS system with the City's other ITS traffic management assets have proven to be very effective tools for promoting coordination with law enforcement. Close coordination between field law enforcement, law enforcement personnel located in the TMC, and City TMC staff has proven very effective in support of special events like the Phoenix Open golf tournament and the Barrett-Jackson Auto Auction. The City's expanded traffic management capabilities have also provided a focal point for sparking greater overall coordination between law enforcement and traffic personnel. It will be important to foster this improved relationship.

As previously mentioned, the future addition of a second dedicated TMC operator is planned in conjunction with expansion of the City's ITS. Ultimately, the addition of a permanent law enforcement representative in the TMC is also desirable. This would further improve coordination with law enforcement during incidents.

3.4.3 Deployment Strategy

The Indian School Road project demonstrates that although Federal funding is generally advantageous, it does reduce the amount of influence the City can exert over the details of the deployment. It also limits the City's flexibility to some extent. For example, Federal ITS funds were administered by ADOT for this project. As such, the City did not have as much control over construction timing as they normally would have over a local street project. Also, ADOT had responsibility for inspections. Their inspectors are experienced primarily with freeway ITS implementations and are not as sensitive to the disruptions to business caused by local street construction.

Keys to the success of the Indian School Road ITS deployment include the following:

- The commitment and dedication on the part of traffic operations staff to utilize the ITS to its full potential and to take advantage of the capabilities provided within the context of an explicit traffic management strategy.
- Early support of senior City management who understood and valued the "ITS vision" and the establishment of an ITS budget. The ITS vision includes increasing the level of responsibility for overall traffic conditions and for actively managing traffic operations to maximize traffic flow under a variety of conditions.
- Having a "champion" at the senior management level to push the program through and the technical staff to follow-through.
- Positive media coverage.
- Continuous experimentation, evaluation, and refinement of traffic management techniques using new ITS tools. The devices are only as effective as the way we use them.

3.4.4 Summary of Lessons Learned

CCTV Cameras

- A critical component of the ITS.
- Installation recommended at major-major and major-minor arterial streets.
- Require routine cleaning—every 3 to 6 months and after rain.
- As additional cameras are added, formalization of current maintenance arrangements (currently performed by City signal crew under an informal agreement) is recommended.
- Both fiber optic cable and T1 communications have proven effective.
- Additional cameras on alternate routes will enable more proactive route guidance strategies.

Radar Traffic Detectors

- More expensive to implement than traditional inductive loop traffic detectors.
- When mounted on existing signal poles it is not possible to achieve the desired coverage area.
- Not currently an acceptable alternative to inductive loops but useful for mid-block traffic counting.
- Since they are mounted above rather than within the roadway they do eliminate the traffic disruptions associated with inductive loop maintenance.
Advancements in this technology should be monitored for potential future utilization.

Video Traffic Detectors

- More expensive to implement than traditional inductive loop traffic detectors.
- Reliability was not satisfactory; sun glare and shadows degrade performance.
- Inability to pan, tilt or zoom severely limits their value for surveillance.
- Not currently an acceptable alternative to inductive loops.
- Since they are mounted above rather than within the roadway they do eliminate the traffic disruptions associated with inductive loop maintenance.
Advancements in this technology should be monitored for potential future utilization.

VMS

- Performed reliably.
- Placement is critical; they should be sufficiently in advance of potential traffic diversion points to allow travelers to read the message and reach and implement a decision.
- Most useful when CCTV cameras are available to TMC staff to visually confirm conditions at the locations referred to in the VMS messages.
- Observations by TMC staff indicate positive driver response to merge messages. Additional feedback on driver responses and the associated traffic impacts will validate hypothesized benefits and support refinements in operating practices.

Operations

- Staff are the most critical component of the ITS. The infrastructure itself does not directly generate benefits; it must be utilized as part of a traffic management strategy.
- CCTV cameras provide the vital information that is needed in order to implement effective traffic management strategies. Nearly all signal timing plan modification and VMS message postings were made based on information collected using the CCTV cameras.
- The addition of a second TMC operator is recommended as the City's ITS is expanded. The addition of a police officer in the TMC will improve the City's ability to eliminate traffic delay associated with incidents.
- At some point as the number of CCTV cameras increases it is expected to become impractical to manually monitor all of them. Advancements that can at least partially automate CCTV monitoring should be tracked.
- VMS messages should be short, concise and easily understood by travelers.
- Expansion of the City's ITS will enable orchestration of traffic management strategies, including traveler information and route guidance, over wider areas.

4.0 BENEFITS

4.1 Summary of Observed and Hypothesized Indian School Road Traffic Benefits

In addition to a wealth of lessons learned that will benefit future deployments, this evaluation confirmed that the ITS technologies do provide the TMC staff with the desired traffic management **capabilities**. It also demonstrated that the staff has made a commitment to **utilize** these capabilities for traffic management in a variety of circumstances, including day-to-day operations, incidents, special events and construction. These conclusions are supported by TMC traffic and law enforcement staff observations, first-hand observation of TMC operations on the part of the evaluation team, and the VMS and signal timing change logs.

Given the many real-world challenges in associating specific traffic management actions with quantitative improvements in traffic conditions in real time, it was not possible to quantify all of the impacts of all of the ITS strategies. Table 6 identifies the traffic related impacts that were either directly observed (e.g., travel time reductions), or which are hypothesized based on previous experience with similar technologies and supported by the qualitative findings of this evaluation.

Table 6
Summary of Observed and Hypothesized Indian School Traffic Benefits

Impact		Impact Observed in Evaluation	Hypotheses Supported by Evaluation
Strategic Traffic Signal Timing Plan Updates Along Corridors	Reductions in corridor travel time.	X	
Strategic Traffic Signal Timing Plan Updates at Individual Intersections	Reductions in the time required for updates via using CCTV for field observations.	X	
Tactical Responses to Recurring (Day-to-Day) Traffic Congestion	Reductions in vehicle delay due to real-time signal timing modifications.		X
Tactical Responses to Special Events	Reductions in vehicle delay due to real-time signal timing modifications.		X
	Reductions in law enforcement field labor hours.		X
Tactical Responses to Incidents and Construction	Reductions in vehicle delay due to real-time signal timing modifications.		X
	Reductions in vehicle delay due to traffic diversions facilitated by VMS.		X

Logic suggests that over time, improved management of incidents, special events, and construction, as well as a reduction in stops at traffic signals during normal peak hour periods will positively impact the number and/or severity of traffic accidents. That is, improved traffic management will minimize the increases in accidents that inevitably accompany traffic volume increases, or will actually reduce the number of accidents. Although this evaluation did add some support to such hypothesis by showing that the ITS devices do provide the basic capabilities that are needed and that staff are committed to using them toward these ends, there is still insufficient evidence to assume such benefits will necessarily occur. Therefore, accident related benefits were not included in Table 6.

It is important to note that there are significant cost savings associated with accident reductions, ranging from about \$2,000 for non-injury accidents to about \$3.2 million dollars for fatal accidents.¹ Elimination of even a very small number of accidents will significantly increase the total benefits of the City's ITS traffic management system.

4.2 Illustrative Benefits Scenario

Based on the benefits that were observed in this evaluation and that are hypothesized, an illustrative benefits scenario has been developed. That scenario includes annualization of benefits, estimated pollutant emissions and fuel consumption reductions associated with vehicle delay reductions, and the dollar value of travel time reductions. This exercise is intended to provide an indication of the types of benefits that are considered likely. It is useful to illustrate how relatively small improvements at one location and in one point in time add up to big savings over time and space. It also illustrates how vehicle delay savings are associated with other important benefits such as reductions in fuel consumption and vehicle emissions.

4.2.1 Benefits Estimation Methodology

This illustrative benefits estimation exercise utilizes the following assumptions:

- 250 travel days (weekdays) per year, consistent with Texas Transportation Institute assumptions for their annual national Urban Mobility Study.
- Vehicle occupancy = 1.10 persons per vehicle for average weekdays, e.g., 90% of vehicles have one occupant; 10% of vehicles have 2 occupants. Average vehicle occupancy = 2.25 during special events like Barrett-Jackson auto auction and Phoenix Open. These are assumed values. For reference, the Maricopa Association of Governments (MAG) values used for regional traffic forecasting range from 1.08 to 1.68 persons per vehicle on weekdays and from 1.12 to 2.08 persons per vehicle on weekends. The higher assumed value for special event traffic is based on informal visual observations made by the evaluation team at the Phoenix Open.

¹ National Safety Council, 2000, information available on web site (<http://www.nsc.org/lrs/statinfo/estcost0.htm>)

- Emission factors for HC (hydrocarbons), NOx (oxides of nitrogen) and CO (carbon monoxide) developed by MAG using Environmental Protection Agency's MOBILE5a model. They reflect the Phoenix vehicle fleet circa 2001 and an ambient temperature of 60 degrees. Emission factors are shown in Table 7.
- Fuel cost = \$1.50 gallon.
- Travelers value their time at a rate of \$13/hour².
- Fuel consumption at idle and deceleration = 0.5 gallons/hour³; and fuel consumption under acceleration = 2.5 gallons/hour (estimated). (For reference, a vehicle that gets 20 mpg at a steady 35 mph consumes 1.75 gallons per hour. The 2001 Corporate Average Fuel Economy standard for passenger vehicles is 27.5 mpg averaged over a highway-city driving cycle that includes cruising speeds, acceleration, deceleration and idling.)
- Health-related costs of emissions from research conducted by the Institute of Transportation Studies, University of California, Davis⁴, as shown in Table 8.

The health-related costs of emissions are very difficult to accurately identify. Values in the literature range widely. Although experts may disagree over the specific values, there is clear agreement that vehicle emissions do cause damage that has a very real dollar value. The assumptions presented here are not intended to support an accurate estimate but rather are intended to illustrate the relationship between vehicle delay reductions and emissions reductions.

Table 7
Emission Factors

Vehicle Speed	Emission Factors (Grams per Hour)		
	HC	CO	NOx
Idle (0 mph)	7.194	56.431	3.134
45 mph	34.200	224.780	96.930

Table 8
Health-Related Costs Per Pound of Emissions

HC	CO	NOx
\$1.38	\$0.11	\$20.31

² Per assumptions used by the Texas Transportation Institute (TTI) in their annual national Urban Mobility Study.

³ Per Scott Sluder, Oak Ridge National Laboratories, March 2003.

⁴ "The Societal Cost of the Health Effects of Motor Vehicle Air Pollution, 1996, McCubbin and Delucchi.

4.2.2 Illustrative Benefits of Observed and Hypothesized Impacts

Benefits are estimated for each observed and hypothesized impact area that was identified previously in Table 6. These estimates are illustrative. They are based on a limited number of observations; additional observations will improve their accuracy. The estimates have been developed using sketch level analytical techniques. The estimates are based on the accomplishments of TMC staff that are still learning and perfecting their approaches; greater benefits are expected in the future. Finally, these estimates do not include many important intangible benefits, like the improvement in overall quality of life that is associated with improved traffic conditions, or the increased satisfaction that results when citizens feel that traffic operations staff are being more responsive to their concerns. These are very important benefits that we can assume will accompany the observed and hypothesized impacts.

Strategic Traffic Signal Timing Plan Updates Along Corridors

The evaluation indicated that traffic signal timing plan updates along the 3-mile Indian School Road corridor resulted in a travel time reductions in three of the four analysis periods and a travel time increase for one of the analysis periods. Table 9 presents the estimated annual benefits associated with these impacts. The methodology for calculating the benefits is presented in Table A in the appendix.

Table 9
Annual Community Benefits of Strategic Corridor Timing Plan Updates

Type of Benefit	Estimated Annual Reduction	Estimated Annual Dollar Value
Person delay	5,477 hours	\$78,324
Fuel consumption	5,477 gallons	\$8,216
Emissions	103 pounds	\$6,883
Total		\$93,423

The emissions and fuel reductions assume that 50% of the travel time savings is stopped time at intersections, when vehicles are at idle; 25% of the time savings is when vehicles are decelerating, when both fuel and emissions are equivalent to idle; and the remaining 25% of time savings is when vehicles are accelerating, when fuel consumption and emissions are significantly higher than either idle or cruising speeds. In an attempt to approximate the higher emissions associated with acceleration, emission rates for 45 mph have been used. This approach is referred to as a “modal analysis” because fuel and emissions are calculated under different vehicle performance modes (i.e., idle, acceleration and deceleration). A more accurate estimate of benefits would require a much more extensive analysis, but the values presented here provide an indication of the relationship between delay reductions and fuel and emissions reductions.

Strategic Traffic Signal Timing Plan Updates at Individual Intersections

The evaluation indicated that traffic signal timing plan updates, those that can be performed based on visual observation, can be done more efficiently using ITS tools. It

was found that 2.1 times as many updates could be performed using CCTV cameras than is currently done using on-site observations. Currently, about 45 updates are performed each year. With ITS, this number could be increased to 95 updates, an increase of 50 updates per year. The evaluation also indicated that using the CCTV cameras three rounds of timing plan refinement were performed, rather than the single round that was done using the on-site observation approach. It is assumed that these additional refinements will result in greater delay reductions.

The benefits of additional traffic signal timing plan updates will depend on a number of factors, including the number of additional updates that can be performed, the number of vehicles benefiting from those updates and the magnitude of the benefits in terms of average vehicle delay savings per vehicle. For the purposes of this illustrative analysis, the following scenario is assumed:

- 50 additional timing plan updates per year.
- Each update reduces average vehicle delay by 10 seconds for each of 500 vehicles during the morning peak hour and 500 vehicles during the evening peak hour, over a period of 60 weekdays.

Table 10 presents the benefits that would be realized given these assumptions. The methodology for calculating the benefits is presented in the appendix.

Table 10
Annual Community Benefits of Additional Strategic Timing Plan Updates
at Individual Intersections

Type of Benefit	Estimated Annual Reduction	Estimated Annual Dollar Value
Person delay	9,167 hours	\$119,171
Fuel consumption	4167 gallons	\$6,250
Emissions	1,208 pounds	\$1,426
Total		\$126,847

Tactical Responses to Recurring (Day-to-Day) Traffic Congestion

Analysis of traffic signal timing modification logs and interviews with TMC personnel indicate that timing plans were frequently updated during normal traffic conditions based on the observation of spot congestion. Based on these logs, it is estimated that approximately 400 timing plan modifications will be made each year and that approximately half of these modifications will be during day-to-day conditions. It is also expected that the number of updates will increase in the future as TMC staff become more focused on this new activity.

This evaluation was unable to quantify the traffic impacts of these types of modifications. However, traffic benefits are produced by these modifications. Based on their visual inspection, TMC staff obviously believes strongly that these modifications have a net positive impact on traffic operations; otherwise they would not make them. In fact, it is not uncommon for staff to try a modification, observe that it does not improve conditions,

and then reset the signal to the original timing. Based on these hypothesized impacts, benefits have been estimated.

The following assumptions are made:

- 500 timing plan modifications are made each year (as noted above, the number is expected to increase significantly over existing levels as staff become more focused and proficient with this new activity).
- Each modification reduces average vehicle delay (idle delay) by 10 seconds for each of 5,000 vehicles each day, over a period of 20 weekdays (about one month).

Table 11 presents the benefits estimated using these procedures. The methodology for calculating the benefits is presented in the appendix.

Table 11
Annual Community Benefits of Tactical Day-to-Day (Recurring) Congestion
Timing Plan Modifications

Type of Benefit	Estimated Annual Reduction	Estimated Annual Dollar Value
Person delay	152,778 hours	\$1,986,113
Fuel consumption	69,445 gallons	\$104,168
Emissions	20,139 pounds	\$23,764
Total		\$2,114,045

Special Events

Hot Spot Timing Plan Modifications

The observation of TMC operations during the Barrett-Jackson auction/Phoenix Open week verified that the TMC staff made a significant number of modifications to traffic signal timing plans in real-time. These modifications addressed “hot spots”—traffic back-ups reported by police officers in the field or observed by the TMC staff themselves using CCTV cameras. Over the course of several hours and numerous modifications, evaluation personnel were able to visually observe reductions in queue lengths following the modifications (e.g., queues that completely cleared during one signal cycle). During these modifications, the queue lengths of other movements at the intersections, movements that did not benefit from the modification, were not seen to visibly increase. The evaluation was unable to capture the traffic data necessary to quantify these impacts, and of course such analysis is required to “prove” benefits. However, it does seem likely that some benefits are being realized through these modifications and the purpose of this exercise is to provide an indication of what the nature and magnitude of those benefits would be given various assumptions.

The following assumptions are made:

- Over the course of the Barrett-Jackson/Phoenix Open week a total of 50 timing plan modifications are made.
- On average, each timing plan modification reduces delay by 10 seconds for each of 500 vehicles.

Table 12 presents the benefits estimated using these assumptions. The methodology for calculating the benefits is presented in the appendix.

Table 12
Annual Community Benefits of Barrett-Jackson/Phoenix Open
Hot Spot Timing Plan Modifications

Type of Benefit	Estimated Annual Reduction	Estimated Annual Dollar Value
Person delay	155 hours	\$2,015
Fuel consumption	78 gallons	\$117
Emissions	10 pounds	\$12
Total		\$2,144

Police Labor Savings

Based on information provided by law enforcement and traffic operations staff at the TMC, the number of police officers in the field for special events has been reduced from 50-55 officers per day to 24 officers, a 40% reduction. This reduction amounts to about 2,976 person-hours over the course of the 12 days of the Barrett-Jackson auction and Open (31 officers/day x 8 hours/day x 12 days). Much of the extra Phoenix Open-related law enforcement staffing is overtime. At an average hourly pay rate of approximately \$36 (per Scottsdale PD), the 2,976 man-hours amounts to \$107,136. Table 13 summarizes these benefits.

Table 13
Police Labor Savings

Number of Field Police Officers Reduced Per Day	Total Person-Hours Saved Over 12-Day Phoenix Open/Barrett-Jackson time Period	Hourly Wage Rate for Field Police Officers	Total Dollar Value of Labor Savings
31	2,976	\$36	\$107,136

Tactical Responses to Incidents and Construction

The evaluation verified that TMC staff proactively and aggressively utilizes the Indian School Road ITS to manage traffic during incidents and road construction. They adjust traffic signal timing plans in real-time to address back-ups and congestion and they post messages on variable message signs. At a minimum, these messages serve to provide travelers with advance warning of delays, which can be assumed to reduce driver frustration. It is hypothesized that many of the more strongly worded messages, especially those advising motorists of long delays, serious accidents or recommending

that they avoid the area, also result in vehicles detouring around construction or incident scenes. It is hypothesized that in some cases these detours save travel time.

Although the evaluation validated that TMC staff frequently employs the system to make these sorts of improvements possible, no hard evidence of these impacts was obtained in this evaluation. Therefore, benefits associated with these impacts are estimated here based on assumed values. These estimates are intended to identify the types of benefits that may be achievable as a result of strategies currently being used by TMC staff and which will be perfected over time.

This estimates assume the following:

- 200 construction/incident-related traffic signal timing modifications are made each year. (The signal timing logs that were analyzed suggest that the total number of timing plan modifications made each year could easily approach 400, and that construction and incident-related changes account for between 150 and 200 of those changes).
- Each traffic signal timing plan modification results in a 10 second per vehicle reduction in intersection (stopped/idle) delay and impacts 1,000 vehicles.
- 150 construction/incident-related messages are posted on VMS each year. (The VMS logs that were analyzed suggest that upwards of 170 messages may be posted over the course of a year, with as many as 80% of those messages pertaining to construction or incidents).
- Of the 170 VMS messages, 50% of them will result in a reduction of 30 seconds of stopped (idle) delay for each of 2,000 vehicles. (Short-term incidents will impact fewer vehicles but long-term construction will impact many more vehicles).

Table 14 presents the estimated benefits based on these assumptions. The methodology for calculating the benefits is described on page A-2 in the appendix.

Table 14
Annual Community Benefits from Tactical Construction
and Incident-Related Traffic Management

Type of Impact and Benefit	Estimated Annual Reduction	Estimated Annual Dollar Value
Traffic Signal Timing Modifications		
Person delay	612 hours	\$7,943
Fuel consumption	278 gallons	\$417
Emissions	81 pounds	\$96
VMS Postings		
Person delay	1,558 hours	\$20,254
Fuel consumption	779 gallons	\$1,169
Emissions	226 pounds	\$267
Total		\$30,146

4.3 Nationally Reported Benefits

The national literature on the observed, quantitative (rather than predicted or qualitative) benefits of traffic signal coordination and other arterial street ITS strategies was reviewed. The purpose of this exercise is to provide additional validation of the City of Scottsdale's traffic operations practices and additional perspective on the results obtained in the Indian School Road ITS evaluation.

Table 15 compiles results from a number of studies of the impact of traffic signal equipment modernization and coordination of traffic signals. Table B in the appendix identifies the individual studies and results of each study. Table 16 compiles results from a number of studies of the impact of centralized traffic signal systems. Table C in the appendix identifies the individual studies and results of each study. The national findings underscore the importance of steps that the City has taken in their traffic management strategy:

- installation of modern traffic signal equipment;
- coordination of traffic signals; and
- centralized traffic signal control.

The benefits of traffic signal timing updates and optimization are widely accepted, as exemplified by these comments from a representative of the FHWA Office of Travel Management: "There are significant benefits to traffic signal retiming. It's very cost-effective in comparison to a lot of alternatives, especially construction. The benefit ratio can be as high as 40:1."⁵ "The FHWA has estimated that as many as 75 percent of all traffic signals could easily be improved by updating equipment or by simply adjusting their timing plans or by coordinating adjacent signals"⁶. The Institute of Transportation Engineers (ITE) identified timing optimization of already interconnected signals as the most cost-effective timing projects⁷. The ITE has estimated that each dollar spent optimizing signal timing could yield a 15- to 20-gallon savings in fuel.

⁵ Pamela Crenshaw, quoted in "Managing Traffic Flow Through Signal Timing", S. Lawrence Paulson, *Public Roads*, January/February 2002.

⁶ Paulson, 2002.

⁷ "Improving Traffic Signal Operations", 1995.

Table 15
Summary of Nationally Reported Benefits of
Signal Equipment Modernization and Coordination Projects

Typical Measures of Effectiveness	Typical Evaluation Methods	Range of Quantified Benefits ⁽¹⁾
<ul style="list-style-type: none"> Travel time Vehicle delay Number of stops Speeds 	<ul style="list-style-type: none"> Field travel time studies (floating car or average speed method) Computer simulation (e.g., TRANSYT-7F) 	<ul style="list-style-type: none"> Travel time reduction = 7% - 22% Delay reduction = 7% - 31% Stops reduction = 13% - 27% Speed increase = 6% Fuel decrease = 2% - 8% CO emissions = no change to +1% HC & NOx emissions = no change Crash reduction = 3 -9% Fatal crash reduction = 1%
<ul style="list-style-type: none"> Fuel consumption Vehicle emissions 	Computer simulation (e.g., TRANSYT-7F)	
Crash risk/crashes	Various, including before/after accident data and estimation/simulation	

⁽¹⁾ Where only one entry appears it means that only one study reported this measure.

Table 16
Summary of Nationally Reported Benefits of
Centralized Traffic Signal Control Systems

Typical Measures of Effectiveness	Typical Evaluation Methods	Range of Quantified Benefits ⁽¹⁾
<ul style="list-style-type: none"> Travel time Vehicle delay Number of stops Speeds 	<ul style="list-style-type: none"> Field travel time studies (floating car or average speed method) Computer simulation (e.g., TRANSYT-7F) 	<ul style="list-style-type: none"> 6% - 42% reduction in stops 16% increase in speed 3% - 44% reduction in delay 9% to 18% reduction in travel time 9% to 13% reduction in fuel consumption 5% to 22% reduction in emissions
<ul style="list-style-type: none"> Fuel consumption Vehicle emissions 	Computer simulation (e.g., TRANSYT-7F, CORSIM, etc.)	

⁽¹⁾ Where only one entry appears it means that only one study reported this measure.

The national literature indicates that there is general agreement that centralized traffic signal control systems are effective. The Texas Transportation Institute (TTI) has written: "Significant benefits accrue from the implementation of one or more of the principal packages that are part of 'traffic control' (*i.e., the Traffic Control User Service identified in the National ITS Architecture*). It is likely that most deployments will produce

statistically significant improvements in key measures, such as crashes, travel times, and delay.”⁸

The literature review indicates that there are little to no published reports with quantitative, observed benefits of arterial street ITS systems that include CCTV cameras and VMS. Hence, the City of Scottsdale and this evaluation are charting new territory. The few studies that have been published dealing with these technologies are oriented to freeways or freeway corridors that include parallel arterial streets and few definitive findings have been obtained. There are a number of “smart corridor” projects either operational or in development around the country, including several in California (the Santa Monica in Los Angeles and the Silicon Valley, East Bay and I-580 in the San Francisco Bay Area), but to date there has been essentially no quantitative evaluation. An evaluation of the Silicon Valley Smart Corridor that will include quantitative measures is planned to begin in 2002.

Although the basic capabilities of these technologies have been demonstrated through freeway projects, and their expected application and benefit on arterial roadways have been articulated, few studies have tested them. The City of Scottsdale is at the forefront of efforts to identify exactly how these proven technologies can be effectively applied.

Researchers and practitioners have identified the need to gather more information on arterial street ITS projects. In July 2000, the FHWA Joint Program Office (JPO), the office responsible for ITS, surveyed the 31 members of a data needs task force organized by the Benefits Evaluation and Cost Committee of ITS America in order to identify and prioritize ITS data needs. The survey results indicate that there is a much more serious need for additional data on arterial street incident management, information dissemination and traffic surveillance than for data on arterial traffic control. As of 2000, the JPO ITS Benefits Database contained a total of 24 entries pertaining to arterial management systems; none of those entries pertained to traffic surveillance, information dissemination or incident management.

As the City continues its ITS program, it will be very useful for ITS staff to conduct an on-going dialogue and exchange of lessons learned with other agencies that plan, operate, and evaluate arterial street ITS advanced traffic management systems.

⁸ “ITS Benefits: Review of Evaluation Methods and Reported Benefits”, TTI, 1998.

5.0 CONCLUSIONS

5.1 Findings – What Have We Learned?

5.1.1 The Technologies

Surveillance cameras are critical; they are eyes and backbone of an effective system. No traffic management strategy can be effective without accurate, timely information. Existing practices relative to camera locations and operation are effective. Additional cameras, especially on parallel routes such as Thomas and Camelback (in the case of the Indian School system) will greatly improve the ability to coordinate traffic diversions.

Traditional loop detectors appear to remain the best choice for signalized intersection traffic detection. Video and radar detectors did not perform as well and are more expensive to install. Radar detectors do appear to be well suited to mid-block traffic counting. Given the in-street maintenance drawbacks of loops, the City should continue to consider new technologies like radar and video that can be maintained without disrupting traffic.

Variable message signs were very reliable. Placement is critical. It is important that VMS be located sufficiently in advance of potential diversion points. They also should be placed so that CCTV cameras are available to confirm the conditions at the locations referred to in the VMS messages.

The central signal system is a critical component of the ITS. The addition of CCTV cameras unlocks the potential associated with the signal system's capability for modifying timing plans remotely from the TMC in real-time.

5.1.2 Impacts

The evaluation verified that the CCTV cameras, centralized signal system, and VMS do provide the TMC staff the intended strategic and tactical traffic management capabilities, and that staff proactively and aggressively utilize these tools. In several cases, the evaluation captured quantitative data proving the value of the tools. In other cases, the qualitative evaluation findings provide further support to the hypotheses that various devices and techniques have a positive impact.

Specific findings include the following:

1. Strategic corridor traffic signal timing plan updates provide significant reductions in delay, fuel consumption, and emissions, as previously illustrated in Table 9. These findings are consistent with the findings of a large number of previous studies.
2. In the future, it is expected that ITS can play a greater role in strategic corridor timing plan updates, reducing the amount of time spent observing conditions in the field.
3. Strategic timing plan updates at individual intersections can be done more efficiently using CCTV for visual observations of traffic conditions instead of on-site

observations. Many more updates can be performed each year using ITS than would normally be possible.

4. More time can be spent perfecting timing plans when using ITS. It is expected that these updates will therefore be more effective.
5. ITS significantly improves TMC staff ability to perform tactical traffic management—to observe conditions and effectively modify traffic signal timing plans in real-time, under day-to-day conditions as well as during incidents, special events, and construction. These modifications should reduce traffic delay, fuel consumption, and emissions.
6. Variable message signs provide traffic operators an ability to communicate important traffic information directly to travelers. These messages should reduce driver frustration, traffic delay and the occurrence of secondary accidents.
7. CCTV cameras and the placement of a police officer in the TMC during special events reduces the number of police officers required in the field to provide traffic observations to the TMC. Stationing of law enforcement personnel in the TMC promotes effective overall coordination between traffic operators and emergency services. This coordination is a key component of the new, proactive, and comprehensive approach to traffic management in the City of Scottsdale.

5.2 Implications – Where Do We Go From Here?

Perhaps the most important finding of this evaluation is that it provides further support for the City's move towards a modern, technology-enabled traffic management philosophy. The goal is a more proactive, responsive and responsible approach to traffic operations that will provide a higher level of service to travelers and that is warranted given today's congested and volatile traffic environment. That philosophy features the following components:

- An enhanced appreciation for the importance of maintaining effective traffic signal timing plans and a commitment to do so.
- An enhanced appreciation for the critical role played by traffic operations personnel, the need to maintain an adequate number of well-trained and capable staff, and to devote the time and attention necessary to develop explicit traffic management strategies and standard procedures.
- Recognition of the responsibility and a commitment to monitor traffic conditions for real-time intervention, which minimizes major disruptive effects of traffic incidents. Anyone who drives regularly experiences traffic congestion under normal day-to-day conditions and knows that incidents, construction and special events—anything that introduces more traffic, alters traffic patterns, provides a distraction or in any way constricts roadway capacity—can create major disruptions.

5.2.1 Implications for Future ITS Investments

Should More ITS be Implemented and How Should Effectiveness Be Assessed?

Expansion of the City's ITS infrastructure appears warranted based on the measured and hypothesized benefits identified through this evaluation, despite some areas where additional information is needed. Future assessments of the effectiveness of ITS investments should consider the following basic metrics:

- *Travel time.*
Travel time is one of the key emerging consensus measures for evaluating traffic conditions. Before-after, test car methods using GPS are the current state-of-the-art measurement system. This sort of performance monitoring is expected to become more and more important in the future as agencies, including the Federal Highway Administration, increasingly establish explicit transportation system performance goals and link goal achievement to investment and funding.
- *Intersection average vehicle delay.*
Intersection average vehicle delay is a traditional measure that remains a very useful single indicator of intersection performance.
- *Accident frequency, severity and duration.*
These measures should be collected for both primary and secondary accidents. Currently, there is no simple way to distinguish secondary accidents in the City's database. An improved understanding of incidents (where, when, how many, impacts, etc.) will improve the effectiveness of City traffic management.
- *Reviews of detailed VMS and signal timing change logs.*
These logs provide valuable information on the manner and frequency of utilization of these devices, the first step in understanding their effectiveness. Currently the logs are maintained completely by hand and available only on hardcopy. In the future, information should be entered into an electronic database so that information can be preserved and analyzed more effectively. Also, it would be very useful to automate the recording of this information. This should be possible given the capabilities of the traffic signal and VMS control software, although it will entail some software customization.
- *Public response to traveler information strategies.*
Resource constraints prohibited this evaluation from investigating public responses to variable message signs. Public feedback should not be the sole basis for determining policy because stated opinions often do not match observed behavior and the public is not always in a position to fully appreciate or assess the value of investments. However, in so much as VMS are useful only to the extent that the public find them useful, public input should be a part of the City's continued assessment of VMS. As arterial street VMS become more common around the country, additional research will also provide input to the City's direction.

- *Labor efficiencies.*

Future assessments of City ITS implementations should consider potential police and traffic personnel labor savings, such as those resulting from ITS-enabled field observations (e.g., replacing field observers with CCTV cameras).

How, When and Where to Expand ITS?

There is no simple formula for measuring which roads “warrant” ITS investment. Unlike traffic signal installations there is no accepted industry criteria or thresholds; the science is still too new. Until additional experience provides such clear criteria, “common sense” approaches are being utilized. These approaches place the highest priority on the most critical roads:

1. High volume roads
2. Roads with above average number and/or severity of accidents
3. Roads that serve special event venues or major traffic generators with cyclical traffic volume spikes, like shopping malls during the holidays.

The benefits of ITS are expected to begin tailing off once traffic volumes reach some absolute roadway capacity. Conversely, the impact of ITS is expected to be less on roads with significant excess physical capacity. However, conditions are expected to be better with ITS than without it under any circumstance.

The most critical ITS components are CCTV cameras and the communications system. Fiber optic cable is the preferred long-term approach given its performance and maintainability. T1 lines are also a viable approach, especially as an interim measure and when obtained at low or no cost through franchise agreements with commercial interests. VMS appear useful, although more information on traveler reactions to VMS messages and the associated impacts on traffic operations are expected to improve VMS effectiveness. Generally, it is preferable to implement ITS along corridors of at least several miles in length. However, spot implementations, especially of CCTV cameras, may be useful for isolated, recurring traffic “hot spots”.

As the ITS program is expanded, infrastructure should not be emphasized over personnel and proper planning and analysis. Infrastructure should not be implemented any faster than traffic operations personnel can effectively utilize it. Time is required for planning and analysis, staff recruitment, and training. The City is off to a great start with a small but committed, competent, and perhaps most importantly, inspired ITS staff. However, as the system grows and as responsibilities multiply, a priority must be placed on maintaining such a staff.

Overall Role for ITS in the City’s Transportation Strategy

ITS compliments rather than replaces traditional physical roadway improvements, like adding lanes. The decision to invest in a physical improvement should never be made until the full compliment of less expensive strategies have been considered, including re-striping and traffic signal timing plan modifications. However, there does come a point where the physical roadway capacity can no longer accommodate day-to-day traffic volumes at an acceptable level of service. Therefore, physical expansion along with a travel demand management policy will remain the primary means for addressing those problems.

ITS can benefit the City of Scottsdale most effectively in two areas. First, ITS improves the ability to perform “daily traffic management”, which consists of the frequent assessment and update of basic timing plans; close monitoring of day-to-day traffic operations and adjustment of signal timing plans; and providing VMS traveler advisory messages based on real-time surveillance. These ITS-enabled activities can serve as an interim measure until physical improvements can be made. Given the current scarcity of municipal resources, such relatively low cost (in comparison to physical improvements) measures are more attractive than ever.

The second way ITS can contribute is to address non-recurring incident-related congestion. Decisions to invest in additional physical roadway capacity are based on current and projected average (day-to-day) traffic conditions. It is obviously not prudent to over-build roadways in order to accommodate the short-term spikes in congestion associated with incidents. ITS provides a very cost-effective means for keeping traffic flowing under these conditions.

ITS is an important new, relatively low cost addition to the City’s toolbox of techniques for providing for safe and efficient transportation. In that regard ITS directly contributes to the community’s goals and objectives, the following in particular:

- Preserve the character and environment of Scottsdale – *to the extent that ITS can help minimize traffic congestion and travel times it helps maintain the quality of the Scottsdale living or visiting experience.*
- Provide for the safe, efficient and affordable movement of people and goods – *ITS contributes directly in this area.*
- Coordinate planning to balance infrastructure and resource needs within budget – *as a cost-effective, low capital infrastructure intensive approach, ITS helps stretch resources.*
- Make government accessible, responsive and accountable so that pragmatic decisions reflecting community input and expectations are made – *ITS allows traffic operators to be much more responsive to public concerns by allowing City staff to address comments immediately.*
- Ensure Scottsdale is fiscally responsible and fair in its management of taxpayer money and assets – *as a cost-effective, low capital infrastructure intensive approach, ITS helps stretch resources.*

The Continuous Improvement Process

As a modern and progressive community, the City of Scottsdale is interested in determining how the latest technologies can be used to maintain and enhance quality of life for its residents. Therefore, the process of examining and testing new technologies—whether for libraries, sewer systems, or traffic management—is by definition an on-going one. This process is never “done”, there is always a new technique or technology that warrants consideration.

This evaluation occurred within the first six months of the system's operation, while staff was still working out the bugs and fine-tuning approaches. Additional observations will provide additional lessons learned that will further improve the effectiveness of the City's approach, especially in regard to VMS effectiveness and ITS impacts on accidents.

Arterial street applications like CCTV cameras and variable message signs, as well as the over-arching strategy of monitoring conditions in real-time and intervening through traffic signal timing plan modifications and VMS messages, are new and still evolving. Based on the promise of these techniques and technologies, the City implemented the Indian School Road ITS. Although a number of questions remain for further analysis, this evaluation suggests that the promise is real and has shown some immediate benefits. It is understood that the City may not be able to justify an outside evaluation of their ITS program on a routine basis, but it is imperative that the spirit of evaluation, of asking hard questions and pushing for results, continue as the ITS program expands and evolves.

APPENDIX

- Benefits Estimation Methodology Examples
- Table A – Benefits calculations for Indian School Road corridor timing plan update (Table 9).
- Table B – Detailed results from national literature review of traffic signal coordination, timing plan update and equipment modernization project benefits.
- Table C - Detailed results from national literature review of centralized signal system project benefits.

Benefits Estimation Methodology Examples

Two examples of the benefits estimation methodology used to generate the results shown in Section 4.2 (Tables 9-14) are presented.

Example 1: Applies to Table 9 (Corridor Timing Plan Updates)

Table A-1 on the following page identifies each step in the calculations, from left to right across the columns, starting with the segment, direction and time period-specific travel time results from the Indian School Road travel time analysis. This calculation is more complicated than the calculations for the other travel-delay-related benefits (Tables 10, 11, 12 and 14) due to the fact that a modal reduction methodology was used for fuel consumption and emissions. That is, project-related delay impacts were assumed to be composed of time increases/decreases under different vehicle operating modes—idle, acceleration, and deceleration—and differing consumption and emission rates were used for these different modes. The method employed here is a sketch-level method, suitable only to illustrate the magnitude of potential benefits and the relationships between traffic delay, fuel and emissions.

Example 2: Applies to Tables 10, 11, 12, and 14.

The delay, fuel and emissions benefit calculations for these impacts utilized a simplified version of the calculations shown in Table A-1. The calculations were simplified based on the assumption that all vehicle delay savings consist of reductions in vehicle idle only. As a result, only idle emission and fuel consumption factors were applied. The following summarizes the steps in these calculations:

1. Estimate total annual vehicle delay savings based on estimated impact of ITS activity, that is, how many vehicles will be impacted each day, over how many days will impacts occur, and how many seconds of delay will be saved per vehicle. The specific assumptions for these variables are presented in the body of the report as bullet items immediately preceding the results tables.
2. Convert total vehicle delay to total person delay by multiplying by an assumed 1.1 average vehicle occupancy for day-to-day conditions (Tables 10, 11, and 14) and 2.25 for the Phoenix Open/Barrett-Jackson auto auction week (Table 12).
3. Estimate dollar value of total annual person-delay savings by multiplying by \$13/hour.
4. Estimate fuel consumption by multiplying hours of vehicle delay saved by 0.5 (gallons of fuel consumed per hour at idle).
5. Estimate dollar value of fuel savings by multiplying gallons of fuel by \$1.50/gallon.
6. Estimate pounds of emissions reduced by multiplying total annual vehicle delay by emission factors at idle (presented in Table 7).
7. Estimate dollar value of emissions reductions by multiplying pounds of each pollutant by the health-related cost (presented in Table 8).

Table A
Benefits Calculations for Indian School Road
Corridor Timing Plan Update (Table 9)

			Daily		Total				Annual							
	Trave	Avg.	Total	Total	Annual	Dollar Value	Annual	Annual	Annual				Annual			
	Time	Peak Hr.	Veh-Sec	Veh-Hrs	Veh-Hrs	of Time	Fuel	Fuel	Emission Reductions				Emission Reductions			
	Change	Directional	of Delay	of Delay	of Delay	Savings to	Savings	Savings	(Pounds) ⁽⁷⁾				(Dollars) ⁽⁸⁾			
Segment, Direction and Time Period	(Sec) ⁽¹⁾	Volume ⁽²⁾	Change	Change	Change ⁽³⁾	Travelers ⁽⁴⁾	(Gallons) ⁽⁶⁾	(Dollars) ⁽⁸⁾	CO	HC	NOX	Total	CO	HC	NOX	Total
AM																
Eastbound West Seg.- 64th - Miller	22.38	657	14704	4.1	1021.1											
Eastbound East Seg. - Hayden - Pima	-5.00	595	-2975	-0.8	-206.6											
Westbound East Seg. - Pima - 82nd	1.63	1621	2642	0.7	183.5											
Westbound West Seg. - Hayden - 64th	-5.63	926	-5213	-1.4	-362.0											
PM																
Eastbound West Seg.- 64th - Miller	-36.93	1337	-49375	-13.7	-3428.8											
Eastbound East Seg. - Hayden - Pima	19.20	1902	36518	10.1	2536.0											
Westbound East Seg. - Pima - 82nd	1.83	944	1728	0.5	120.0											
Westbound West Seg. - Hayden - 64th	-65.67	1171	-76900	-21.4	-5340.2											
Total	-68.19		-78871.6	-21.9	-5477.2	\$ (78,324)	-5477.2	\$ (8,216)	-1190	-168	-321	-1679	\$ (131)	\$ (232)	\$ (6,520)	\$ (6,883)
⁽¹⁾ Results of travel time study																
⁽²⁾ From 24-hour traffic counts conducted as part of the evaluation																
⁽³⁾ Assumed 250 typical workday weekdays per year																
⁽⁴⁾ Assumed \$13/hour and 1.1 people/vehicle																
⁽⁵⁾ Assumed 25% of total time saved would have been under accel. (2.5 gal./hour) and remainder of time savings at decel. or idle (0.5 gal./hr)																
⁽⁶⁾ Assumed price of gas is \$1.50/gal.																
⁽⁷⁾ Assumed 75% of total time saved would have been idle or decel. and 25% of time would have been under accel. Emission factors (per MAG) are"																
CO = 56.43 grams/hr (idle and decel.); 224.78 grams/hr (at 45 mph, surrogate for accel.)																
HC = 7.19 grams/hr (idle an decel.); 34.2 grams/hr (at 45 mph, surrogate for accel.)																
NOX = 3.13 grams/hr (idle and decel.); 96.93 grams/hr (at 45 mph, surrogate for accel.)																
(In all cases to convert grams to pounds, multiplied by .002205)																
⁽⁸⁾ Assumed the dollar values identified in Table 8 of the report.																

Table B
Signal Coordination, Timing Plan Update and Equipment Modernization -
Summary of National Evaluation Results

Study	Project Type	Project	Evaluation Method	Quantitative Evaluation Results
<p>"ITS Benefits: The Case of Traffic Signal Control Systems"</p> <p>University of California at Berkeley, 2000</p>	<p>Signal Coordination (Time of Day)</p> <p>Signal Operation Modification</p>	<p>Signal timing optimization, coordination, and adaptive signal control projects implemented under the California Fuel Efficient Traffic Signal Management (FETSIM) and City of Los Angeles Automated Traffic Surveillance and Control (ATSAC) Programs.</p>	<p>Benefits of signal optimization based on TRANSYT-7F model estimates for 6,701 signals and using before and after field studies using floating car data collection. Benefits of signal coordination based on before and after field studies using floating car data collection.</p>	<p>17:1 B/C ratio for all FETSIM projects</p> <p><u>Signal retiming (estimated):</u></p> <p>7.7% reduction in travel time</p> <p>13.8% reduction in delays</p> <p>12.5% reduction in stops</p> <p>7.8% decline in fuel use</p> <p><u>Signal retiming (observed):</u></p> <p>7.4% reduction in travel time</p> <p>16.5% reduction in delay</p> <p>17% reduction in stops</p> <p><u>Signal Coordination (observed):</u></p> <p>11.4% reduction in travel time</p> <p>24.9% reduction in delays</p> <p>27% reduction in stops</p>
<p>"Phoenix Metropolitan Model Deployment Initiative Evaluation Report"</p> <p>FHWA, 2000</p>	<p>Signal Coordination (Time of Day)</p>	<p>Coordination of signal cycle lengths for 8 of 21 signals along a corridor that crossed two jurisdictions.</p>	<p>Floating car studies and computer simulations. Computer simulations examined both coordinated scenarios and scenarios with signal optimization without coordination.</p>	<p><u>Floating car studies:</u></p> <p>6.2% increase in vehicle speeds,</p> <p>1.6% reduction in fuel consumption,</p> <p>1.2% increase in CO emissions</p> <p>No change in HC or NOx emissions</p> <p>6.7% reduction in crash risk along mainline</p> <p><u>Computer simulation:</u></p> <p>21% reduction in AM peak delay (coordination)</p> <p>16% reduction in AM peak delay (optimization w/out coord.)</p>
<p>"Metropolitan Model Deployment Initiative Seattle Evaluation Report"</p> <p>FHWA, 2000</p>	<p>Signal Coordination (Time of Day)</p>	<p>Coordination of fixed traffic signal timing plans across jurisdictional lines.</p>	<p>Estimated benefits based on computer modeling.</p>	<p>7% reduction in vehicle delay</p> <p>No change in vehicle emissions</p> <p>2.5% reduction in crashes</p> <p>1.1% reduction in fatal crashes over 10 yrs</p>
<p>Palmdale 10th St. W/Avenue P</p>	<p>Signal Operation Modification</p>	<p>In 1997, the City of Palmdale initiated efforts to improve traffic signal timing</p>	<p>Before and after evaluation using the following variables: travel time, stops</p>	<p>.50 to 2.0 tons of total emission reductions</p> <p>35% to 55% increase in fuel efficiency</p>

Table B
Signal Coordination, Timing Plan Update and Equipment Modernization -
Summary of National Evaluation Results

Study	Project Type	Project	Evaluation Method	Quantitative Evaluation Results
City of Palmdale, CA	Signal Coordination (Time-of-Day)	plans along 2 major corridors serving a regional mall. The proposed solution was to optimize signal timing along these two corridors.	delays and number of stops. Implementation of PASSER/NETSIM/Synchro Signal Optimization was the primary tool used in deriving "After" Travel Time Evaluations	(MPG) 4:1 to 11:1 B/C ratios
"South Bay Signal Synchronization and Bus Speed Improvements Project Grant I: Summary of Before and After Study Results" Meyer, Mohaddes Associates, 1997	Signal Coordination (Time of Day) Signal Operation Modification	Signal equipment upgrades (e.g., communication gap closure, new detectors and controllers) and retiming of 300 traffic signals to improve coordination along four arterial roads in the southern portion of Los Angeles.	Before and after travel time studies using floating car technique, per MTA's guidelines.	4:1 B/C ratio Travel time reductions of 13% and 20% found for some segments.
"The Benefits of Computer Traffic Control" Wilshire, 1969 Traffic Engineering	Signal Controller Modernization	Replaced mechanical, single dial signal controllers with computerized (solid-state) controllers.	Field data.	16% reduction in stops 31% reduction in vehicle delay 8.5% reduction in accidents 50% increase in speeds
"A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility" ITE, 1997	Signal Coordination (Time of Day)	Coordination of traffic signals across jurisdictions.	Unknown	7% to 22% reduction in travel time (Denver, CO)

Table C
Centralized Traffic Signal Systems - Summary of Evaluation Results

Study	Project Type	Project	Evaluation Methodology	Quantitative Evaluation Results
<p>"Traffic Signal Optimization for Tyson's Corner Network Volume I. Evaluation and Summary"</p> <p>Virginia Department of Transportation, 2000</p>	Centralized System	System to connect approximately 700 signalized intersections with central control. Communicates over leased telephone lines to a central control room. In the control room, operators can monitor traffic conditions at the intersections and can retime signals as needed.	Not available	<p>6% reduction in stops (saving \$418K) 22% reduction in system delay (\$18 M) 9% reduction in fuel consumption (\$1.5M)</p> <p>Total annual emissions for CO, Nox, and VOC estimated to be reduced by approximately 134,600 Kg.</p> <p>Annual savings to motorists traveling network estimated at near \$20 million</p>
<p>"ITS Benefits: The Case of Traffic Signal Control Systems"</p> <p>University of California at Berkeley, 2000</p>	Centralized System (Traffic Responsive Signal Control, "Critical Intersection Control" (CIC))	City of Los Angeles Automated Traffic Surveillance and Control (ATSAC) System. Computerized, interconnected and coordinated signal system in operation since 1984. As of 1994, it included 1,170 intersections and 4509 detectors for signal timing optimization. The green demand for each phase is calculated every cycle, while the cycle length and offsets remain fixed to maintain coordination.	Evaluated seven intersection locations using real-time detector data from the ATSAC Detector Analysis Report, CIC timing splits from the ATSAC Detector Analysis Report and existing fixed-time time-of-day signal settings from existing timing charts.	<p>3.1% to 16.2% delay reduction V/C change from +4.7% to -14% LOS improved on avg. 25% of cycles LOS unchanged on avg. 73% of cycles</p>
<p>"Automated Traffic Surveillance and Control (ATSAC) Evaluation Study"</p> <p>City of Los Angeles, 1994</p>	Centralized System (Traffic Responsive Signal Control, "Critical Intersection Control" (CIC))	Computerized, interconnected and coordinated signal system in operation since 1984. As of 1994, it included 1,170 intersections and 4509 detectors for signal timing optimization. Traffic is monitored with detectors and traffic surveillance cameras and various timing programs are automatically implemented in response to fluctuating traffic demands.	Travel time studies using the average speed method, conducted along corridors in three portions of Los Angeles: Westwood/West Los Angeles, Ventura 1/Ventura 2a, and Airport. Based on field data on times, stops and delay, estimated emission and fuel consumption. Reported benefits reflect changes relative to pre-ATSAC signal timing strategies.	<p>41.5% reduction in vehicle stops 18.1% reduction in travel time 16.0% increase in average speed 44.2% decrease in delay 32:1 overall benefit cost ratio</p>
"How to Save \$4.2 Million a Year"	Centralized System	Central Business District	Four routes evaluated in the	9% to 14% reduction in travel time

Table C
Centralized Traffic Signal Systems - Summary of Evaluation Results

Study	Project Type	Project	Evaluation Methodology	Quantitative Evaluation Results
Hetrick and McCollough, 1996 ITS International Newsletter		centralized traffic signal system including 262 intersections located in Richmond, VA.	field to identify travel time, delay and stops. Fuel consumption and emissions estimated.	14% to 30% reductions in total delay 28% to 39% reductions in stops 10% to 12% reduction in fuel consumption 5% to 22% reduction in emissions.
"Making Waves in Traffic Control" Beteille and Briet, 1997 Traffic Technology International Annual Review	Closed-Loop/Areawide Systems (Traffic Responsive)	Traffic signal system in Paris, France that features automatic selection of timing settings to favor pedestrians, by time of day.	Unknown	20% reduction in "journey times" 30% reduction in number of stops 10% reduction in fuel consumption
"Benefits of the Texas Traffic Light Synchronization Grant Program 1: Volume 1" Texas Department of Transportation, 1992	Closed-Loop/Areawide System Centralized System	Phase I consisted of arterial and network signal systems including 2,243 signals in 44 cities. Phase II included an additional 73 systems.	Unknown	62:1 B/C ratio overall <u>City of Abilene Closed-Loop System:</u> 13.8% reduction in travel time 22.2% increase in speed 0.3% increase in number of stops 37% reduction in delay 5.5% reduction in fuel consumption 12.6% reduction in CO emissions 9.8% reduction in HC emissions 4.2% reduction in NOx emissions